EVALUATION OF COMPUTERIZED LAYOUT ALGORITHMS FOR USE IN DESIGN OF CONTROL PANEL LAYOUTS

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EVALUATION OF COMPUTERIZED LAYOUT ALGORITHMS

FOR USE IN DESIGN OF CONTROL PANEL LAYOUTS

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SUMMARY

This study examines the applicability of computer-aided design to the configuration of a man-machine system, an army aircraft instrument panel. CRAFT, CORELAP, and PLANET, three facility allocation algorithms, were chosen to be adapted for this purpose. Particular emphasis was put on deriving a design methodology.

The current techniques and practices of instrument design were reviewed in light of the military methodology. Actual flight test data was used in applying the design methodology, and the resulting computer generated layouts were analyzed for their usefullness by comparison with standard practices, and the results show that this technique could be used effectively by the aircraft panel designer. In addition, this methodology is considered for placement into the military design procedure.

Suggestions for further study and limitations of the research are included.

CHAPTER I

INTRODUCTION

Purpose of the Research

Rotary wing aircraft have become more important to military operations since the Korean War, until now where they are an integral part of the logistics team as well as the combat fighting force. A likewise development in the civilian community has brought the helicopter into everyday life, as police patrol, cropdusters, traffic reporters, and intra-city transportation. Even though there has been a quantum jump in the use of rotary wing aircraft over the past twenty years, the man-machine coupling through the cockpit instrument layout for the helicopter has not kept pace. Techniques are currently subjective and artisan in nature. As with the development of the helicopter, computer technology, for design purposes has also made vast strides in the past two decades. In the field of industrial and system engineering, there exists a large number of facility allocation algorithms used for plant layout type problems. The purpose of this study is to evaluate the usefullness of three of these algorithms, CRAFT, CORELAP, and PLANET, when applied to the instrumentation problem for a standard army helicopter.

Problem to be Studied

The instrumentation problem for rotary wing aircraft is a many faceted question and is one that is shown to involve both control and display[23]. Display can be broken down to such categories as instrument design, heads up display (HUD), heads down display (HDD), panel layout, and others. However, panel layout design will be the area of the instrumentation problem that will be studied here because it fits into the context of the computer algorithms and does not require a technical knowledge of instrument theory and design. To lessen the problems of standardization and data collection, a standard army helicopter instrument panel (SAHIP)(Figure 1) for a UH-1B helicopter will be used. Therefore, using the shape and size of the example instrument panel and its associated complement of instruments, the problem to be studied here is how applicable is computer-aided design to a SAHIP.

There has been very little work done on this specific problem; Bartlett[4] showed the feasibility of this approach. However, there has been considerable research in computer-aided design and the instrumentation problem on an individual basis both by government agencies and civilian institutions, but very little effort has been expended into the realm of computer-aided design of instrument panels.

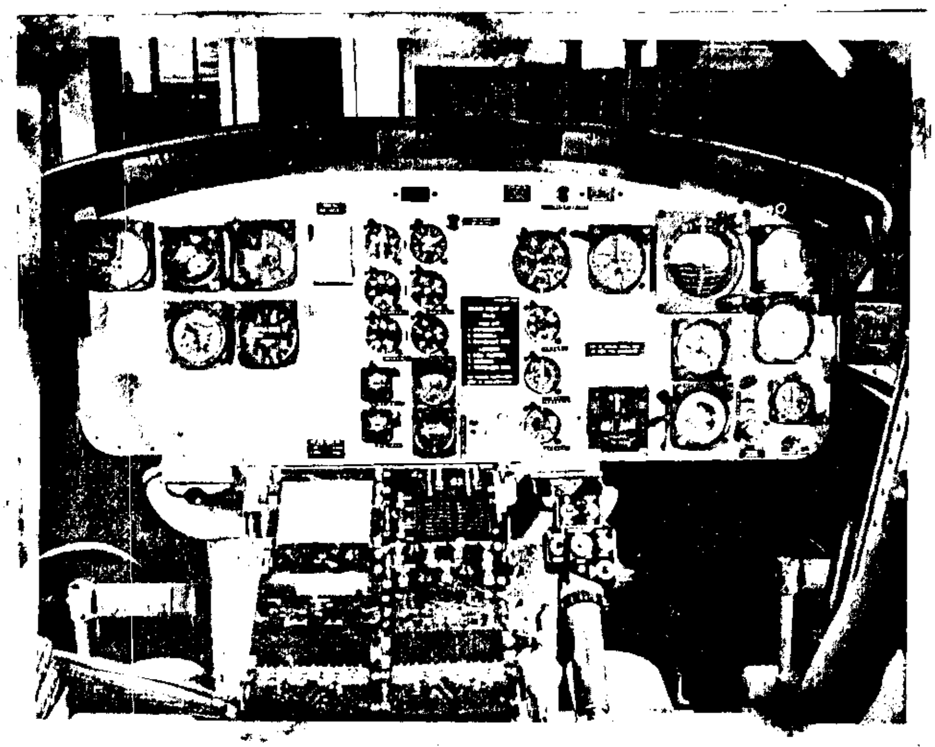


Figure 1. UH-1 Cockpit

CHAPTER II

CURRENT TECHNIQUES, PRACTICES AND KEY DESIGN CRITERIA FOR A SAHIP

Constraints of the Army Requirement and Procurement System

At the present time, control panel layout design is in a transitional stage, especially for army helicopters. The full utilization of the rotary wing concept is severely hampered by the outmoded instrumentation that is being used. The instrumentation that is used was designed for conventional fixed-wing aircraft and does not allow the helicopter to fully utilize its unique flight envelope, the real bonus obtained from rotary wing flight.[22]

This transitional stage of layout design is not linked so much to the lack of theory, knowledge, and practical tools, as it is to the lack of strong requirements, the interaction between requirements, and the procurement system and the doctrine that has developed in aviation from just before World War II to the present. The state of the art is on the brink of implementing new ideas, concepts, and procedures with the traditional and doctrinal approaches, already in use, to produce a well defined methodology for solving the panel layout problem.

However near panel layout design is to a new methodology, it is still saddled with the traditional techniques, practices, etc., that are used on a day to day basis. To better understand the current process of panel design, it is necessary to first understand the constraints of the system that procures army aircraft.

In most cases, there is an initial requirement generated within various channels for a certain type of aircraft with specific capabilities. This requirement is given to civilian contractors for proposed designs and prototypes generally after a program manager and budget are set. At other times, however, the contractors come to the army with their own proposal. The program manager, an army officer with an independent charter from the highest levels of command, is the man that interprets requirements, capabilities, limitations, and is the authority with whom the civilian contractor must deal. He is not bound to advice from any technical command in the army, but he seeks information based on hard facts, which tends to place an amount of personal bias (into the final product).

The budget that the program manager has to work with is usually very tight and he is bound to keep costs low and make savings where possible; this is the overriding consideration in most instances. An associated constraint of the budget is the workload analysis of the pilot and other crewmembers; the funds for this type of study must come out of the program manager's budget, which severely limits depth of information gathered to meet actual requirements in past history.

Traditionally, aircraft procurement is centered around well documented requirements for performance, this tendency puts the emphasis on aircraft performance and not on instrumentation. To gain more consideration in the area of instrument panel design, etc. continuing emphasis is being placed on the need for better instrumentation to the program managers through the technical commands of the army. Also, since the army not only buys specific pieces of equipment but spare parts, special tools, and training packages, the cost of a specific item is much greater than buying a commercial model with a warrantee, as other services do. The net effect is a lower level of performance from the equipment purchased, which makes new requirements for more sophisticated gear difficult to obtain because of the associated high cost.

The above constraints are those on the system, but there are others which pertain directly to the instrument panel. First, there are army regulations that require specific primary instruments and radios for different types of aircraft. Second, in the requirements list for the aircraft there may be a special mission device that must be installed, such as a night vision device or weapons sight/actuator system. Another constraint that plays an important role is the availability of instruments and radios from commercial manufacturers in the quality, quantity, size, shape, weight, capability, and cost required. And finally, the constraint of area available for the panel layout. Since aircraft are presently designed around aerodynamic qualities such as speed, load capability, endurance (range), serviceability, with priority over the pilot's ability to perform the assigned mission, the panel layout design is given certain depth, area, shape, and weight restrictions by the aeronautical engineer, and the panel designer must plan the layout to meet those requirements.

Taking into consideration all the above-mentioned constraints on the panel layout, the design practices can be viewed in proper perspective. The current design technique can best be described as a "jury" system, and it should be noted that the instrument panels of current operational army helicopters were designed by the contractor and then accepted by the army.

The jury system consists of several artisan designers, armed with the constraints of area available, army regulations, military specification for the particular aircraft, instruments available and previous experience making a cockpit mock-up and then using paper and cardboard cutouts to come up with several designs using current doctrine such as the basic "T". The basic "T" is the traditional pattern used for fixed-wing aircraft instrument panels that places the basic flight instruments of airspeed, attitude, altitude, and heading into a "T" configuration. Airspeed, attitude and altitude are in a row with the heading instrument placed under the attitude instrument. The contractor's staff of test pilots and the program manager are then brought in for a "trial", and any changes are produced by "tuck and fit" on the mockup. Minor changes may be made in the test flight program, but the "jury" system prevails for instrument panel layout design.[13]

New Methodology

As stated before, instrument panel design is in a transitional state. This metamorphosis of design techniques was precipitated by the more complex aircraft components and a variety of strenuous mission assignments. This new methodology also considers the entire cockpit interior including special mission devices, aircraft controls, armor protection, and survival gear. This new concept of design was patterned after a JANAIR (Joint Army Navy Aircraft Instrumentation Research)

research program and designed to maximize effectiveness and simplify airborne operation.

This methodology is a systematic technique of breaking down information requirements to lower levels starting with the mission requirements, aircraft configuration, and specific avionics package. Each critical mission area is identified and broken down into its component items from the mission analysis. Each mission item is then broken down into functions or tasks and these tasks are then analyzed for necessary actions and decisions to identify control and display requirements. In this early design phase, it is paramount that all participating contractors and government agencies are made aware of cockpit requirements before starting the design of the aircraft to preclude conflicts between cockpit and aircraft.

A mock up is then made of the instrument panel for sizing, arranging, and evaluating the specifications. This preliminary mockup phase is followed by a pilot time-based workload evaluation. Then a final full scale mockup. Figure 2 shows the major phases of a cockpit configuration. The pilot time-based workload analysis is made up of a Matrix Analysis and a Time Load Analysis. The Matrix Analysis uses a matrix format and provides a detailed look at instruments and displays to make sure they are related to a specific mission requirement (Figure 3). The time load analysis is used to determine the operability of the proposed layout by examining pilot tasks against time in a mission context and the attention required to accomplish the task. Then a final full scale mockup is produced which is then integrated into the aircraft's airframe structure.[19]

Major Phases of the Study

For analysis and documentation purposes, several major phases have been identified as follows:

Phase 1. Mission Requirements Analysis. This activity consisted of an analysis based upon the mission, aircraft, and equipment data furnished by the Government.

Phase 2a. Functions/Task Analysis. This is a further breakdown of the major areas identified in the mission analysis. The functions/task analysis is taken down to the actions and decisions necessary to accomplish the mission.

2b. Preliminary Mockup. This consists of "CORE FOAM" and cardboard utilized primarily for analytical purposes in sizing, arranging and trading off C/D layouts.

Phase 3. Matrix Analysis. For this analysis, each function/task identified in the functions analysis is subjected to individual analysis for display, control, and implementation analysis.

Phase 4. Time-Based Load Analysis. This analysis evaluates the operator load in accomplishing the mission requirements.

Phase 5. Final Mockup. This is a full-scale mockup that can be used to show the generic cockpit configuration. It contains photographic prints of the control display units on the instrument panel and the center and overhead consoles. (Four Required)

Figure 2. Phases of Study

The results from the research being conducted is intended to be used in Phase 2b and Phase 5 of the new military methodology to provide the panel designer with another tool in configuring panel layouts. This will allow him to consider many more layout configurations and to conduct a parametric analysis of instrument positions if a new instrument is introduced with no previous data.

MATRIX ANALYSIS: III. SUMMARY OF C/D MECHANIZATION ANAL-OBSERVER TASKS

*** OTHER

NO.	TASK	CONTROLS: ROT-ARY	ALT/ ACT	MOM	CONT RATE	***	TYPE	DISPLAYS: VSD	HSD	NAV	ENG	SENS	WARN	***	TYPE
0001	A/C ILLUMINATED?	NONE											X	X*	*RHAW CRT
0002	A/C OK?	NONE						NONE							
0003	ACQUIRE BRG TO DOWNED A/C	X					DETENT ROTARY	X		X*					*NAV COU
0004	ACQUIRE SCOUT A/C VISUALLY	NONE						NONE							
0005	ACTIVATE CIRCUIT BREAKERS		X				PUSHBUTTON	NONE							
0006	ACTIVATE LASER		X				TOGGLE							X	SWITCH POS
0007	ACTIVATE LASER TRACKER		X				TOGGLE							X	SWITCH POS
0008	ACTIVATE READOUT SWITCH			X			PUSHBUTTON							X	SWITCH POS
0009	ADD SYMBOLS			X			PUSHBUTTONS	X				X		X*	*SWITCH POS
0010	ADJUST ANTI COLLISION		X				TOGGLE							X	SWITCH POS
0011	ADJUST AUDIO	X					CONTINUOUS ACTION	NONE							
0012	ADJUST AUDIO GAIN	X					CONTINUOUS ACTION	NONE							
0013	ADJUST BORESIGHT ZERO		X				CONTINUOUS ACTION	NONE							
0014	ADJUST CONTRAST	X					CONTINUOUS ACTION	NONE							
0015	ADJUST DEFOGGING		X				TOGGLE							X	SWITCH POS
0016	ADJUST DIOPTER					X		NONE							
0017	ADJUST DISPLAY BALANCE	X					CONTINUOUS ACTION	NONE							

06062

Figure 3. Matrix Format

CHAPTER III

COMPUTER-AIDED DESIGN

Computer-Aided Design

Computer-aided design is a technique used in the overall design process to increase the effectiveness of the designer. By its very nature, computer-aided design means a close relationship between man and the computer by various means, such as visual displays (graphics), terminal keyboards, computer printouts, and other means. This man-computer interface has proven an extremely effective tool in all types of design problems. Architectural and aircraft designers have been prime proponents of computer-aided design, however many fields are using it on a daily basis.

Computer-aided allows a design engineer to test many more ideas and configurations than was possible by manual means, and enables him to rapidly see the effect of a hypothesis and modify the hypothesis accordingly. This capability fits directly into the "iterative design process" (Figure 4). This procedure is normally used because a design cannot be synthesized directly, but it is possible to analyze a trail design, vary the inputs, and converge on a solution. Each time a pass is made in the design loop, the design is closer to the optimum. Computer-aided design permits the designer to make many more passes in the design loop, therefore providing a better and quicker solution. This is the thrust behind testing the facility allocation algorithms for instrument panel design. Currently, only a few configurations can be analyzed, whereas, computer-aided design could allow the panel designer to analyze many more configurations.[18]

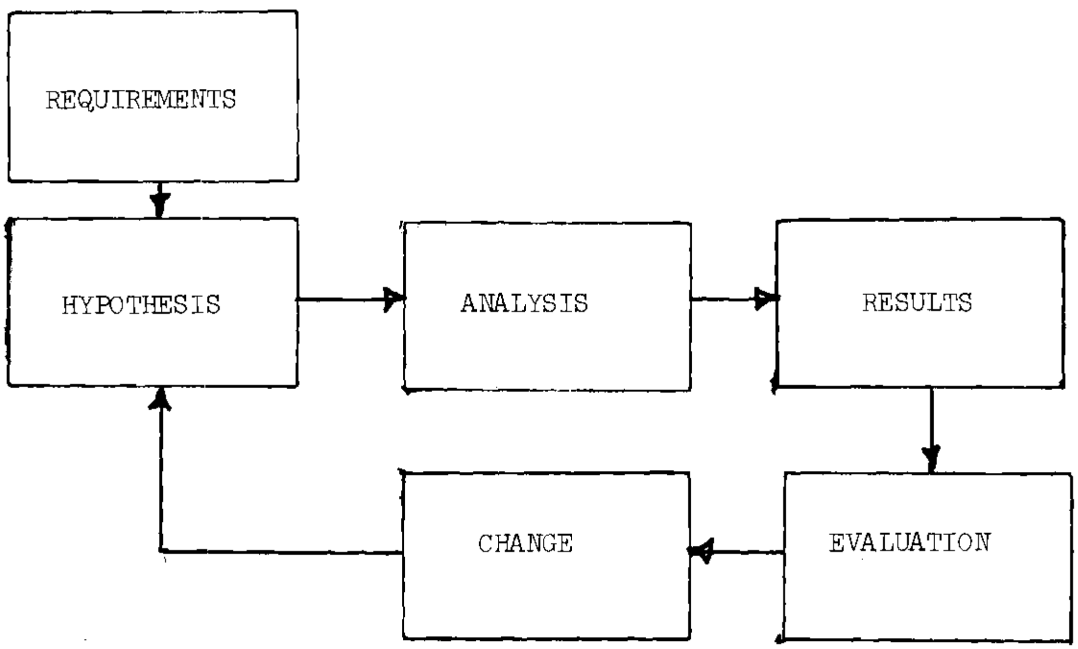


Figure 4. Iterative Design Process

General Nature of the Algorithms

The algorithms that are being analyzed in this study are CRAFT, CORELAP, and PLANET. Each of these facility allocation algorithms has been implemented successfully on a variety of industrial plant layout type problems. CRAFT and CORELAP have found rather wide use and acceptance in the industrial complex, while PLANET was recently developed at Georgia Institute of Technology. Even though there exists mathematical formulation for the layout problem, a computationally feasible algorithm for producing an optimal solution still is in the offering. These algorithms were developed because of the increased size and complexity of the layout problem. Traditional layout techniques were unable to handle the growing number of departments involved, the many complex material flow patterns, and the large volume of data to be analyzed. These heuristic computer algorithms are able to handle the enormity of the problem, and provide a solution to the layout problem, even though they do not guarantee optimality.[7, 14]

CRAFT CRAFT

CRAFT (Computerized Relative Allocation of Facilities Technique) was one of the original models to be developed for the plant layout problem, and takes the heuristic approach by starting with an initial layout (provided by the designer) and iterating by exchanging two departments, which best improves the layout, until an exchange provides no improvement in design. Improvement in design means that the handling cost of the layout is decreased. Handling "cost" is determined by distance moved, the cost of material flow, and the volume of material flow.[7,14]

Input for CRAFT can be summarized into three categories which correspond to the three quantities necessary to compute the handling cost, initial layout, matrix of handling costs between each pair of departments, and matrix of material flow. Once these are stored in the computer, the program runs as depicted in Figure 5. Departmental exchange can occur if both departments are the same size, and have a common side, both departments have a common side with a third department. The procedure for choice of exchanges is made by the user as shown below:

1. Both Departments are the same size.

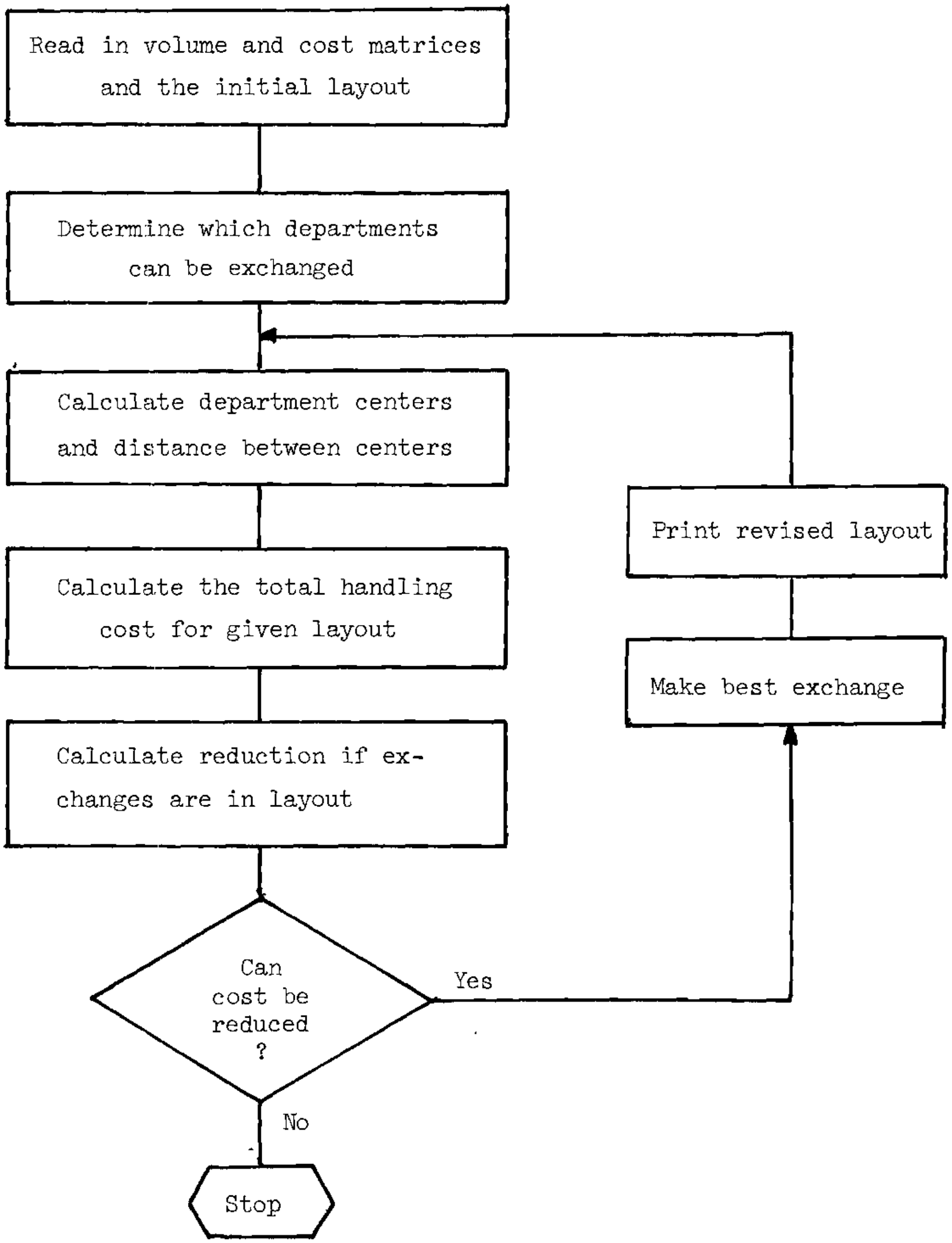


Figure 5. General Flow for CRAFT Program

2. They have a common border.

3. They both border on a common third department.

The first two conditions are used for a "two department" exchange while the third involves a "three department" relayout. CRAFT offers the user the choice of which of the exchanges is to be used:

1. Two department moves only.

2. Three department moves only.

3. Two department moves followed by three department moves.

4. Three department moves followed by two department moves.

5. Choose best of two or three department moves at each iteration.

The output of CRAFT contains the input data, a matrix which is the product of matrix multiplication of the cost and volume matrices, the final layout, and intermediate layouts if the designer indicates this option. CRAFT can be used to quantify the material handling cost of a layout produced by another method, thus it can be used to assist in comparison.[1, 7]

CORELAP

The second algorithm to be considered is COmputerized RElationship LAyout Planning, otherwise known as CORELAP. It is a digital computer program that was designed to produce a layout of departments without requiring an initial spatial input, as in manufacturing problems where CORELAP permits the establishment of departmental areas before a building configuration is made, and to do this economically. CORELAP is a path oriented algorithm that builds up a layout by adding one department at a time in a systematic way until the final layout is achieved. The same final layout will be produced from the same input data.

The input for CORELAP consists of four components, the number of departments, data from the Relationship Chart (REL), a table of area requirements for each department included in the REL, and the maximum length to width ratio of housing for the layout of departments. This variable input data is used in producing the reference files that are used in the main part of the computer program.[16]

There are basically two questions that make up the main portion of the algorithm. These are:

1. Which department will enter the layout next?
2. How is this department entered?

The department with the highest total closeness ratio (TCR) is entered into the layout and placed in the center of the building. This department is designated the "winner." Next, a search is initiated in REL matrix to find a "candidate" that has an "A" highest closeness rating with this department. The higher TCR value is used to break any ties between candidates. The department that is chosen is placed in the layout, recorded by name, and designated "victor." The algorithm looks for other candidates with "A" ratings with the previous winner and places them in the layout. If an "A" rating cannot be found, then all the "victors" are checked to see if they have an "A" rating with a candidate. If one is found, the "victor" is designated the "winner" and the candidate is entered into the layout. If an "A" rating cannot be found between the "winner" or any "victor", then the closeness rating is decreased and the search continues.

A "sweep routine" places the "victor" into the layout by examining the layout for available space next the the winner. If space is available the victor is placed here. If space is not available next to the "winner", available space is sought one step at a time further away from the "winner."

The output from CORELAP is a layout matrix that represents a block plan layout. The location of the departments is indicated by printing a two-digit number code for the department in each of the unit squares that it occupies. Zeros are used to indicate unused squares. Intermediate layouts are printed each time a department enters the layout in the same fashion as described above.[7, 16]

PLANET II

PLANET II was developed at Georgia Institute of Technology by Deisenroth[7] from previous work done by Gani, to provide a spatial arrangement of activity areas or departments within facilities. The intention behind the development of PLANET II was to produce a design with a "low" material handling cost that would give a layout in the initial design mode that could be adapted into a logical configuration by the layout designer. This program was not intended to produce a total design for a facility nor does it select the best layout available. It is to be used as an interactive tool to aid the design engineer in solving the layout problem, since nonquantitative factors usually constrain the selection of the layout to be used.

Input for this program is composed of five different types of cards which can be divided into three categories, run data cards, departmental requirements cards, and flow specification cards. The run data card specifies layout name, number of departments, size of unit block, and program options. Departmental cards, one per department, supplies the name of the department, department identifier, area requirements, and placement priority which is an option. Flow specification cards contain information on material flow within the facility. There are three different formats that can be used, parts lists cards, from-to chart cards, and penalty matrix cards.

First, the program transforms the input data into a usable form before preceding the main algorithm. To construct the spatical arrangement, the algorithm asks two questions until assignment of all departments is complete: first, what department should be selected next; second, where should it be placed? Unlike CRAFT, PLANET II does not require an initial layout, since the program enters one department at a time. Departments are selected by one of three methods:

A.) "Highest flow between cost" for the first pair, then highest cost between a department available to enter and one already in the layout.

B.) Identical with A for the first pair, then each succeeding department is chosen by relating each available department to all departments in the layout, then selecting the department with highest flow cost as compared to all those in the layout.

C.) A flow between chart is constructed which gives cost from one department to each of the others, then each element of the row is added together to obtain a total department cost and then the departments are ranked in order of highest total department cost; departments are entered in order of ranking. Departments are placed in the layout to maintain a low materials handling cost. The first two are placed side-by-side in the middle of the layout; the remaining departments are placed to increase the handling cost by the smallest amount. In this procedure, the perimeter of existing layout is associated with entrance cost, so the minimum cost point is searched for on the perimeter. This point is used as an approximation of the center of the department that entered. This method of placement produces a spiral-like layout as in Figure 6.

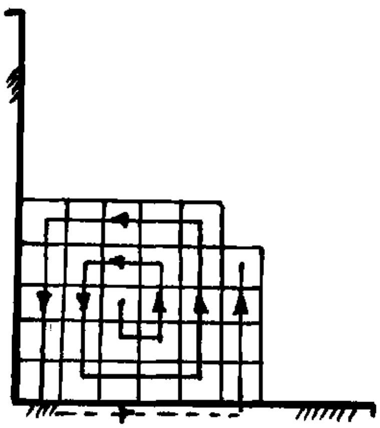


Figure 6. The Spiraling Routine Placing Department Blocks

The output of PLANET II provides a listing of the input data for verification, printout of the From-To chart and flow-between cost chart, and printout of each of the final layouts produced by the three different selection methods as described above.(7)

Constraints and Limitations

Each of the algorithms being studied here have special operating considerations, based on their structure. These special operating considerations take the form of constraints on the designer and his problem or limitations of the program. For purposes of this study, no difference will be made between the different forms of operating considerations. The following is an overview of each of the algorithm's constraints and limitations as the program would be generally used, and not oriented towards panel design.

CRAFT's limitations as listed below seem rather lengthy indeed. However, this program has proved very successful in application and competition with other algorithms.[8]

Constraints and Limitations of CRAFT

1.) Requires hand adjustment (output not directly usuable).

2.) Program tends to be "shortsighted," may not find best answer by switching only two or three departments at a time.

3.) Department switches must be

   A.) the same size

   B.) adjacent to each other

   C.) border on a common department

4.) Input data needs careful structuring.

5.) Letter designation is cumbersome.

6.) Requires a starting solution.

7.) Better adapted to rearrangements.

8.) Undesirable relationships are not accounted for.

9.) Limited to 40 departments.

Constraints and Limitations of CORELAP

1.) Cannot specify fixed activity locations.

2.) Does not calculate cost.

3.) Limited to 45 departments.[2]

The list of constraints and limitations for CORELAP is short compared to the list for CRAFT, but historically hasn't produced quite as good results in the final layout as CRAFT.[8] However, there has only been a few studies done in this area. PLANET II has several constraints and limitations that are important:

1.) Needs actual application and experimentation.

2.) Distances computed by rectilinear measurement in finding material flow cost.

3.) Material handling as controlling factor which emphasizes transition sequence and expected volume of flow.

4.) Input data needs structuring.

The most significant one appears to be the first. Only practice with and experimentation on can prove the worth of the program. The above is a capsulated view of the constraints and limitations of the three different algorithms, the impact of the above information will be seen in Chapter IV, which describes the application of the algorithms to the problem.

The following is a table of comparison of the algorithms.

Table 1. Comparison of the Algorithms

	CRAFT	CORELAP	PLANET II
Maximum Number of Departments	40	45	99
Building Shape	Initial layout required, constrained	No initial layout, unconstrained	No initial layout, unconstrained
Departments	Flexible	Square building blocks	Square building blocks
Date Needed	1. Interdepartmental flow 2. Handling cost 3. Initial layout	1. Number of departments length/width ratio 2. REL Chart 3. Area required for each department	1. Number of departments size of unit block 2. Departmental area requirements 3. Flow specification

CHAPTER IV

METHODOLOGICAL TECHNIQUES

Design Criteria

Finding appropriate criteria for analyzing the man-machine interface is always a significant problem. Sutiable criteria are not always available or the traditional ones are not appropriate in the particular instance. When an operations research technique is applied to the behavioral problem of the man-machine interface, a new dimension is added to the criterion problem, the criteria must be able to be translated into mathematical language. This requires that the criteria used must be a composition of behavioral significance and operational feasibility.

Since computer-aided design is being applied to the instrument panel layout problem, the criterion that is used must be operationally compatible with that technique and suitable information must be available. Dorris[10] discusses various design criteria appropriate to the instrument panel layout problem. These include:

A.) McCormick's Principles:

1.) Components should be arranged with regard to their importance to the system objectives.

2.) Frequency-of-use should be considered.

3.) Sequence of use should be considered.

The criterion problem is very important when applying an operation research methodology to a behavioral problem. Suitable criteria are not always available or the traditional ones are not appropriate in the particular instance, so that the criteria used must be a composition based on behavioral significance and operational feasibility.

B.) Freund-Sadosky "Utility Cost" Concepts:

1.) Product of distance measures and fixation frequency.

2.) Product of probability of transition and sum of the distances from the center of the instrument location to center of every other location.

C.) Clement, Lex, and Graham:

1.) Locate centrally those displays having the highest probability of fixation.

2.) Locate peripherally adjacent to the center of those displays having highest link values with central display.

3.) Locate peripherally remote from the center those displays having lowest link values.

D.) Hitchings, Freund and Sadosky:

1.) Minimization of total eye movement.

It is this last criterion that was adapted for use in this study. It is readily adapted into the frame work of facility allocation algorithms and the information available. Since these algorithms try to minimize material handling costs, thus by viewing link values between instruments as the cost in the facility allocation programs, the program then operates to minimize eye movement. The lower the cost of the layout, the smaller the amount of eye movement. Applying these heuristic computer techniques with the minimization of eye movement criterion allows the panel designer to handle realistic layout problems that can not be solved by optimal producing methods such as used by Dorris.[10]

Adaptation of Computer Algorithms

General

The adaptation of the candidate algorithms to instrument panel layout design was accomplished with little difficulty. The "link" values obtained from the army eye movement study[22] were "two-way link values." To fit this type data into an appropriate input form for the candidate algorithms, the link values were divided by two as an approximation to one-way link values since one-way link values were not available. Link values for the instruments associated with a fixation point involving several instruments were each given the value associated with that fixation point.

Instrument dimensions and associated data were obtained from direct measurement from an actual instrument panel installed in an aircraft. The squares obtained in the output of the computer programs loses no generality since most instruments are housed in square packages even though a round dial is used as the instrument face. For the instruments that are actually round without a housing, a circle inscribed within the square satisfies the need of position and center of mass (Figure 7).

CRAFT

CRAFT was readily adapted to the panel layout problem. Of the

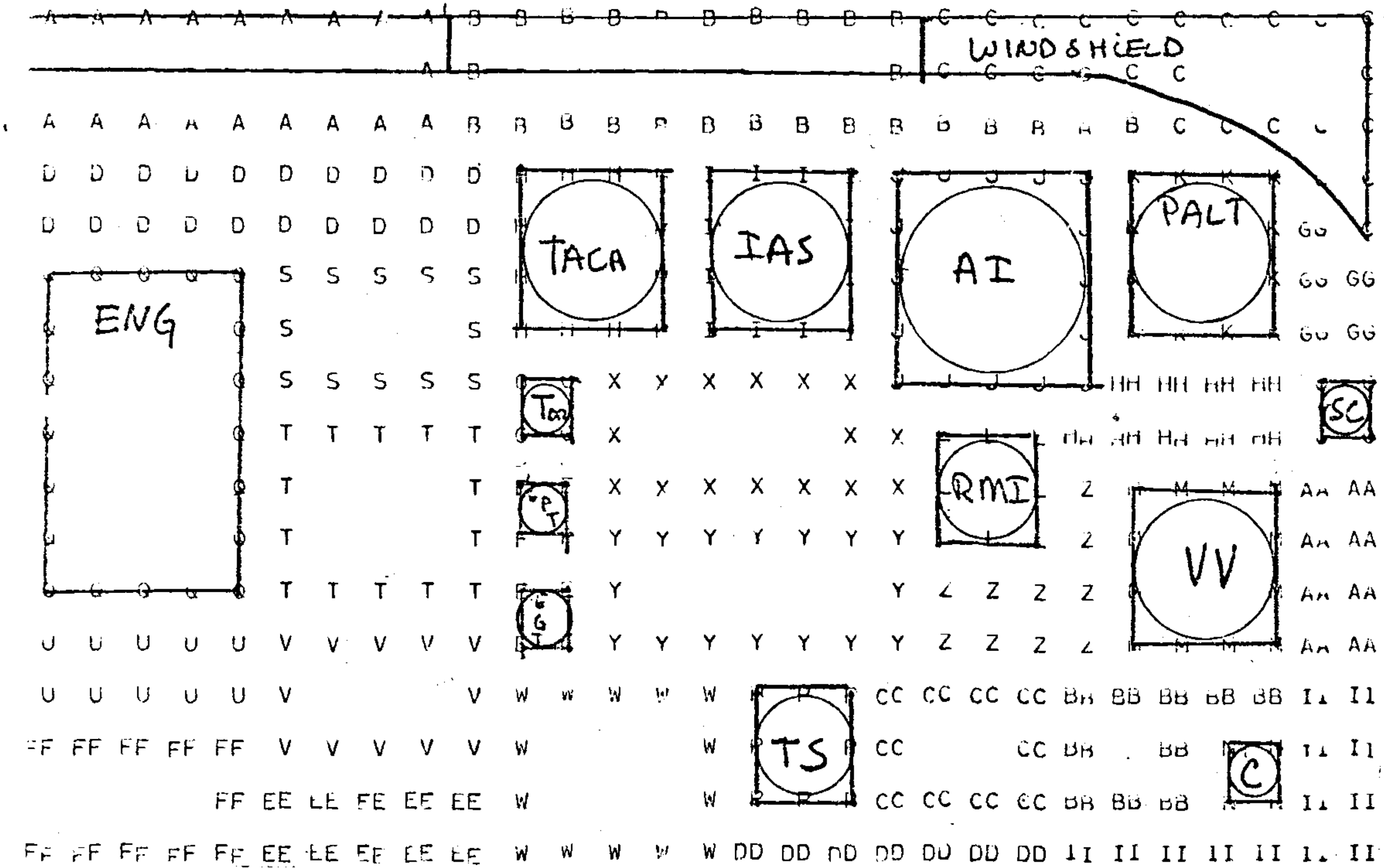


Figure 7. Panel Layout

three programs used, the input preparation for CRAFT was the most time consuming, however, it was not excessive. Three hours were required to construct the FROM-TO-CHART from the link values and one-half hour to construct and/or update initial layouts. Once the FROM-TO chart was constructed for CRAFT, elements could be used to simplify input requirements for the other programs. Figure 8 is the FROM-TO-CHART constructed from the link values and was used to construct the cost array matrix, the volume array matrix consisted of 1's (one's) so that when the two were multiplied together the cost array matrix would be unchanged. This was necessary to maintain the sense of minimizing eye movement, since the link values are the indicators of eye movement.

The program was modified in the CIDST subroutine to use direct distance instead of rectilinear distance for computations. After analysis of the output layout and manual adjustment to maintain instrument shapes, there was little difference between the two methods.

The initial layouts were constructed on the basis of the actual UH-1B instrument panel on a 1 to 1 correspondence, one block on the printout represented one square inch on the instrument panel. The right thirty inches of panel was used since this is the area where the instruments are located that pilot uses and is the natural break point between pilot and copilot areas. The layout was configured by use of fixed departments to conform the shape and size of the actual panel, and provide a reference for link values with outside fixation points, these areas were considered the windshield. The coded blocks lettered

	D	D	D	D	EGT	GPT	TQ	RPM	IAS	ATT	PALT	RMI	VV	C	SC	TS	ENG	D	....	D
D																				
D																				
D					.01	.01	.065	.065	.075	.05	.10					.01	.21			
D																				
EGT			.01				.03	.03	.05	.02	.01	.01	.01				.01			
GPT			.01				.03	.03	.04	.01	.01	.01	.01				.01			
TQ			.065		.03	.03			.215	.11	.055	.04	.04			.03	.12			
RPM			.065		.03	.03			.225	.11	.035	.02	.02			.03	.18			
IAS			.075		.05	.05	.215	.225		.28	.12	.055	.055			.05	.12			
ATT			.05		.02	.02	.09	.09	.26		.55	.17	.335	.01	.055	.02				
PALT			.10		.01	.01	.015	.015	.10	.61		.195	.455	.01	.08	.01				
RMI					.01	.01			.035	.17	.195		.165	.01	.03	.01				
VV					.01	.01			.015	.335	.465	.165		.03	.03	.01				
C										.01	.01	.01	.03		.02					
SC										.035	.06	.01	.01	.02						
TS			.01				.03	.03	.04	.01	.01	.01	.01				.01			
ENG			.21		.01	.01	.12	.14	.12							.01				
D																				
⋮																				
D																				

Figure 8. From-To-Chart

A, B, C, and D on the printout show the fixed areas. Areas A, B, and C were used as the windshield for outside reference. Area D was used as a spacing margin from the top of the panel due depth restrictions of the panel (see Figure 9). The empty area between instruments was broken down into many dummy departments to facilitate movement of the instruments during placement in the program. Three different initial panel configurations were used. The first was the basic panel as used in the standard UH-1B; the second was basic layout, but making all the primary flight instruments the same size to facilitate interchanges in the program; and the third layout was an arbitrary panel, but constructed to violate the basic doctrine of the "T" configuration of airspeed, attitude, altitude, and heading instruments as is found in the other initial layouts. Computer runs were made with these initial layouts.

CORELAP

The ISYE Department's version of CORELAP was found to be in error and not producing layouts according to the CORELAP flowchart. However, it was easily used in panel layout design. The FROM-TO-CHART used for CRAFT was used to generate the REL chart matrix. The mix of REL values is shown below:

(Acceptance Level/Value)	(% of Total Values in Chart)
A (6)	3
E (5)	8
I (4)	16
O (3)	21
U (2)	52
	100%

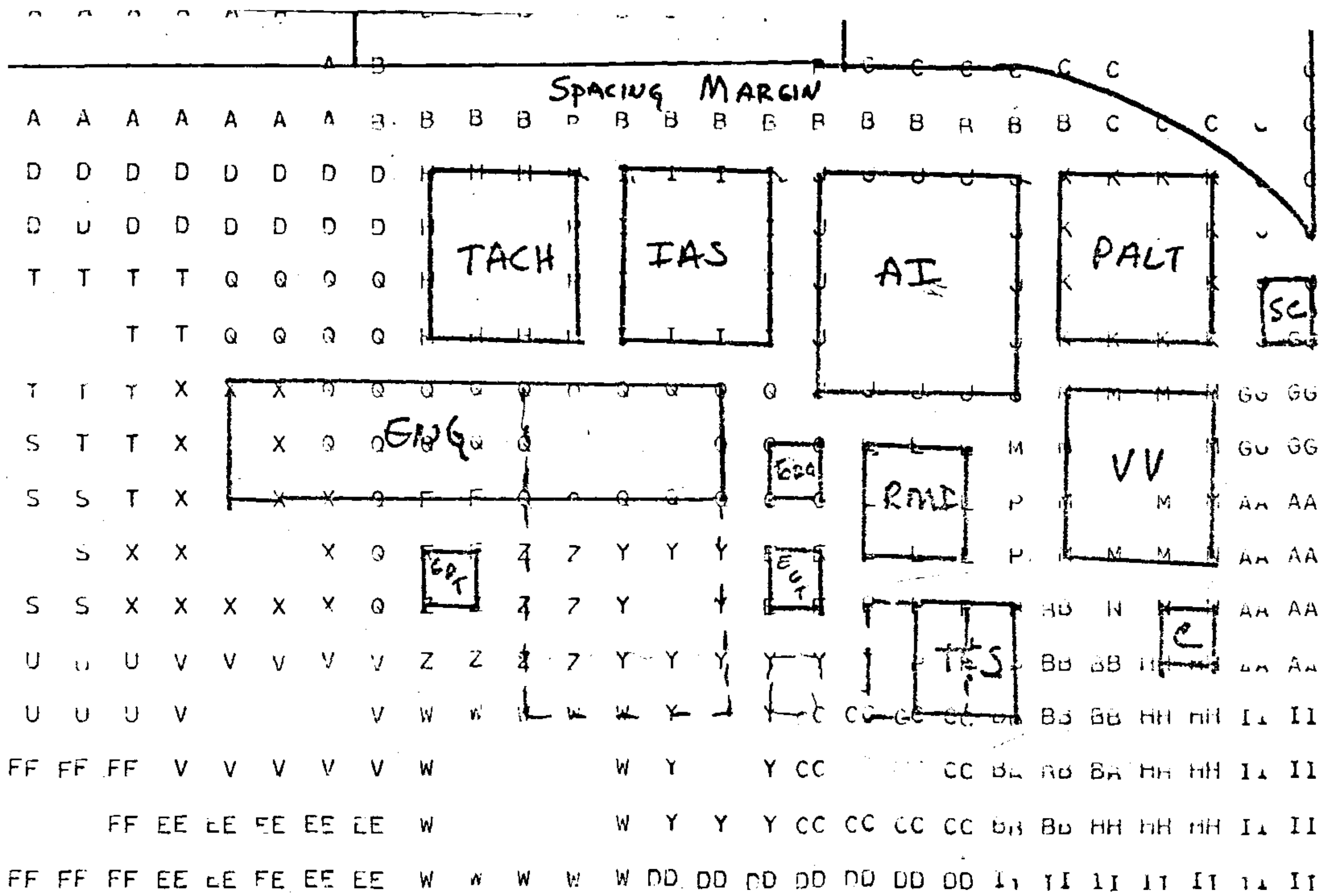


Figure 9. Panel Layout

Range of link values from FROM-TO-CHART associated with acceptance levels

$$\begin{array}{rcl} .40 < & A & \leq 1.0 \\ .20 < & E & \leq .4 \\ .08 < & I & \leq 0.20 \\ .03 < & O & \leq .08 \\ 0 < & U & \leq .03 \end{array}$$

These values were easily put into the REL Chart Matrix (Figure 10). The rest of the input was also readily available. One square inch was used as the size of the building block to maintain the proper scale and ease of interpretation. The closest whole number was used for instrument areas. The same departments were used as in CRAFT. The only problem in adaptation that was encountered was in using the length to width ratio. The actual panel has about 2:1 length to width ratio, whereas the lowest recommended value to use in the program is 4:1. Since the program was in error this problem could not be resolved.

PLANET

The adaptation of PLANET was the easiest of all the programs used. The flow specification was entered in the form of a FROM-TO-CHART as was used in CRAFT, the only change in using this information was multiplying the data by one thousand to obtain whole numbers, example .195 became 195. This was necessary because PLANET normalizes the data and only looks at the first five decimal places; using such small numbers as .195 meant that inaccurate values were used in computation because of the process of truncation. Otherwise there were no special procedures used for applying the program to the panel layout problem. A modification of input was tried to obtain information concerning the relationship between the flight instruments without the

	EGT	GPT	TQ	RPM	IAS	ATT	PALT	RMI	VV	C	SC	TS	ENG	OUT
EGT	0	0	2	2	3	2	2	2	2	0	0	0	2	2
GPT	0	0	2	2	3	2	2	2	2	0	0	0	2	2
TQ	2	2	0	0	5	4	3	3	3	0	0	2	4	3
RPM	2	2	0	0	5	4	3	3	3	0	0	2	4	3
IAS	3	3	5	5	0	5	4	3	3	0	0	3	4	3
ATT	2	2	4	4	5	0	6	4	5	2	3	2	0	3
PALT	2	2	3	3	4	6	0	4	6	2	3	2	0	2
RMI	2	2	3	3	3	4	4	0	4	2	2	2	0	0
VV	2	2	3	3	3	5	6	4	0	2	2	2	0	0
C	0	0	0	0	0	2	2	2	2	0	2	0	0	0
SC	0	0	0	0	0	3	3	2	2	2	0	0	0	0
TS	0	0	2	2	3	2	2	2	2	0	0	0	2	2
ENG	2	2	4	4	4	0	0	0	0	0	0	2	0	5
OUT	2	2	3	3	3	3	2	0	0	0	0	2	5	0

Figure 10. REL Chart

influence of looking outside the aircraft. This was done by deleting the data associated with the link values of the outside references.

Data Source

The data source used for this study was obtained from the Human Engineering Laboratories (HEL) through the Aberdeen Research and Development Center at Aberdeen Proving Ground, Maryland. The army has conducted several studies on eye movement and information transfer associated with helicopter instrument panels.[21, 22] These reports concerned the pilot's eye movements, transitions between instruments, and fixation points, as they pertain to his performance in the cockpit. This information was gathered to assist in development of the new series of army helicopters; in particular, the reports concerned a tactical utility helicopter that would have three basic missions: utility transport, rescue and fire support similar to the mission of the UH-1B used in the study. These missions were analyzed for specific information requirements necessary to accomplish all crew tasks involved, and further narrowed for analysis of the pilot's information needs. Conventional instrumentation was used in the UH-1B for the army reports (Figure 11). Two different mission profiles were created for twenty minute test flights that covered the information requirements deduced from the mission analyses. The major emphasis, from these analyses, was placed on instrument flight but information from visual climb and hover segments of the missions was included; since operating under instrument flight rules (IFR) is a higher pilot workload situation. Figures 12 and 13 depict the different mission plans and profiles.

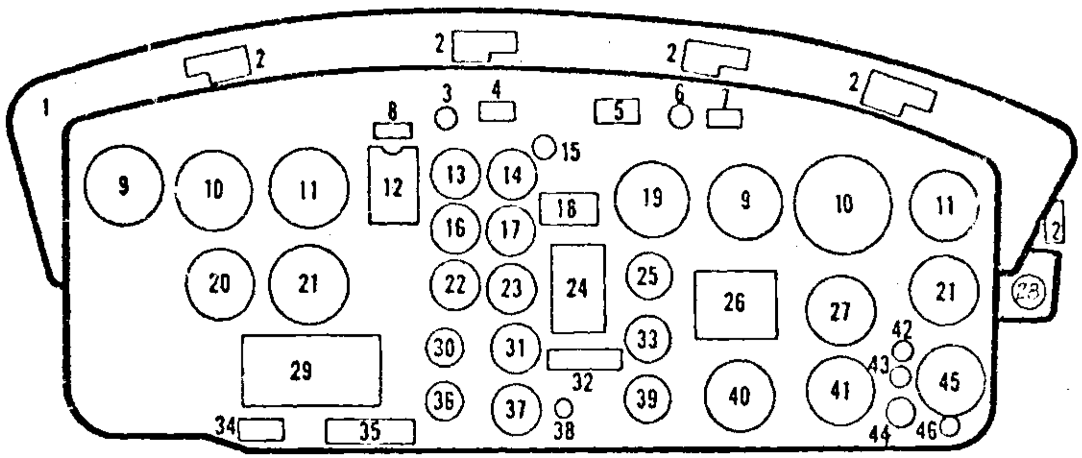


Figure 11. UH-1B Panel Mockup

1. Glare Shield
2. Secondary Lights
3. Engine Air Filter Light
4. Radio Call Designator
5. Master Caution Light
6. RPM Warning Light
7. Fire Detector Test Switch
8. Fire Warning Indicator Light
9. Airspeed Indicator
10. Attitude Indicator
11. Altimeter
12. Compass Correction Card Holder
13. Fuel Pressure Indicator
14. Fuel Quantity Indicator
15. Fuel Gage Test Switch
16. Engine Oil Pressure Indicator
17. Engine Oil Temperature Indicator
18. Cargo Caution Decal
19. Dual Tachometer
20. Radio Magnetic Indicator
21. Vertical Velocity Indicator
22. Transmission Oil Pressure Indicator
23. Transmission Oil Temperature Indicator
24. Pilots Check List
25. Torquemeter Indicator
26. Go-No-Go Take-off Data Placard
27. Radio-Magnetic Indicator
28. Standby Compass
29. Operating Limits Decal
30. Main Generator Loadmeter
31. DC Voltmeter
32. Engine Caution Decal
33. Gas Producer Tachometer Indicator
34. Engine Installation Decal
35. Transmitter Selector Decal
36. Standby Generator Loadmeter
37. AC Voltmeter
38. Compass Slaving Switch
39. Exhaust Gas Temperature Indicator
40. Turn and Slip Indicator
41. Omni Indicator
42. Marker Beacon Light
43. Marker Beacon Volume Control
44. Marker Beacon Volume Control
45. Clock
46. Cargo Release Armed Light

MANEUVER	START	END
Take Off	00:00	
Hover, IGE	00:00	00:02
Vertical Climb	00:02	00:04
Cruise, IFR	00:04	00:07
Standard Rate Turn, IFR	00:07	00:08
Climb, IFR	00:08	00:09
Cruise, IFR	00:09	00:12
180° Turn, IFR	00:12	00:13
Steep Approach IFR	00:13	00:15
Hover, OGE, VFR	00:15	00:16
Vertical Descent	00:16	00:18
Land		00:19

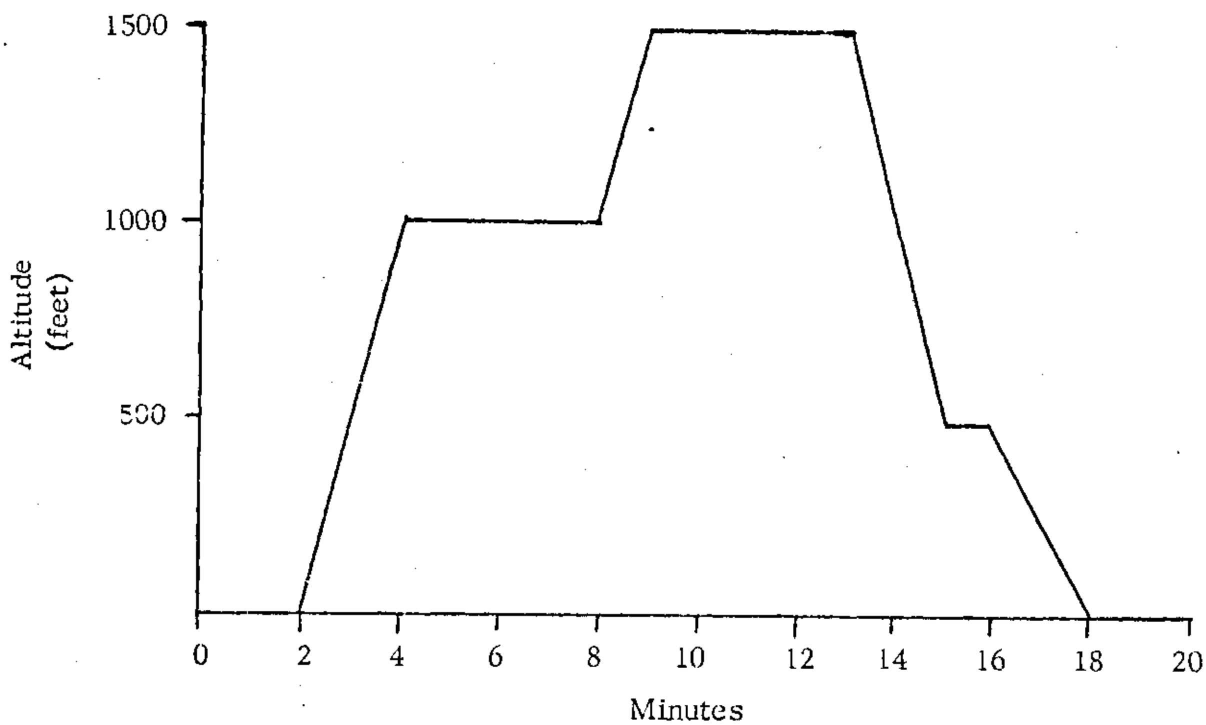


Figure 12. Mission Profile I

MANEUVER	START	END
Take Off	00:00	
Climb, IFR	00:00	00:03
Cruise, IFR	00:03	00:06
Standard Rate Turn	00:06	00:07
Cruise, IFR	00:07	00:10
Descent, IFR	00:10	00:12
Descending Turn, IFR	00:12	00:13
360° Hovering Turn, VFR	00:13	00:16
Descent	00:16	00:18
Land		00:19

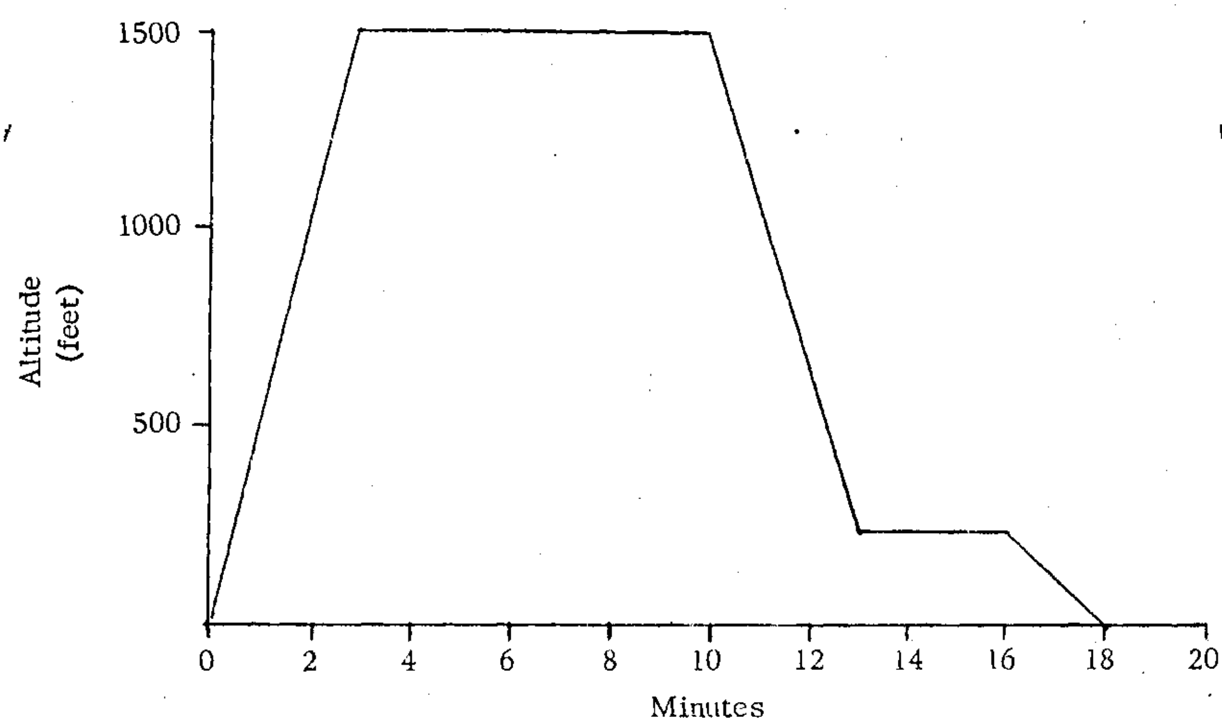


Figure 13. Mission Profile II

The data for eye movement, fixation, and transitions was obtained by the use of the EMC-2 camera fitted to a helmet worn by the pilot (Figure 14). By using this camera system, points of instantaneous eye fixation are recorded on film. Thus by analyzing the projected film, eye movement transitions, and fixation points can be determined. The principle behind this technique is the use of a secondary image, a white dot, superimposed over the pilot's field of view on the film.

> In each frame the dot indicates the exact point of eye fixation at the instant of exposure . . . this image is created by corneal reflection of a pinpoint of light trained on the subject's left eye . . . the shape of the cornea causes the position of the reflected light to change with eye movement, accurately indicating the point of instantaneous eye fixation.[21]

A detailed analysis of the camera, specifications, and calibration techniques can be found in TECHNICAL MEMORANDUM 7-70.[21] Appendix A contains an example of raw data obtained from viewing the various films produced by the camera system.[21,22]

Data Preparation

The raw data gathered from analyzing the films was put into the same format as used by Tetts, Jones, and Milton so that further comparison with their work could be conducted with a minimum amount of effort. The following symbology was used in preparation of the results in TECHNICAL MEMORANDUM 11-72.

TR Duration of run in seconds

Ti Sum of time spent fixating on a point/instrument

$\overline{\text{Td}}$ Mean fixation/dwell time

Ni Sum of fixations on a point/instrument

Nu Sum of fixation not identified because of blinks, movement,

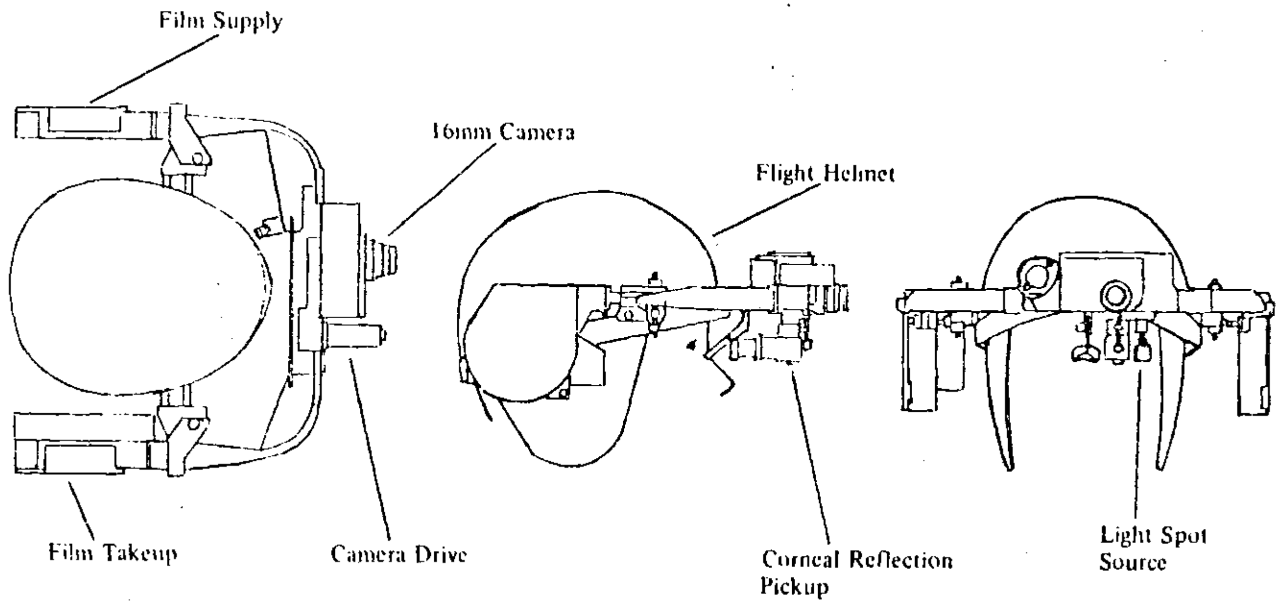


Figure 14. Eye Movement Camera System

movement beyond system units, etc.

n Dwell fraction; portion of run time spent on a point

M Sum of fixation points

$\overline{f_s}$ Scan rate

Nm Sum of fixations on all fixation points

Where

$$T_R = T_2 - T_1 \frac{\text{Run end time (frame number)}}{\text{frame rate}}$$

$$T_i = \sum_{k=1}^{Ni} T_{ik} \text{ (unit is in seconds)}$$

$$\overline{Td} = \frac{1}{Ni} \sum_{k=1}^{Ni} Td_k = Ti/Ni \text{ (unit is seconds/fixation point)}$$

$$\overline{f_s} = Ni/T_R \text{ (unit is fixation/point/run time)}$$

$$n = Ti/T_R \text{ (unit is sum of fixation time/run time)}$$

$$N = Nut \sum_{i=1}^{M} Ni \text{ (unit is fixations)}$$

Tables were constructed using the film data and the above symbology as an intermediate step to determining link values. Tables for visual maneuvers listed fixation points by their location from the center of the pilot's windshield (Figure 15 a and b). The following are the abbreviations used:

A - Ahead, center of pilot's windshield

L - Left, ½ the distance to the left edge of pilot's

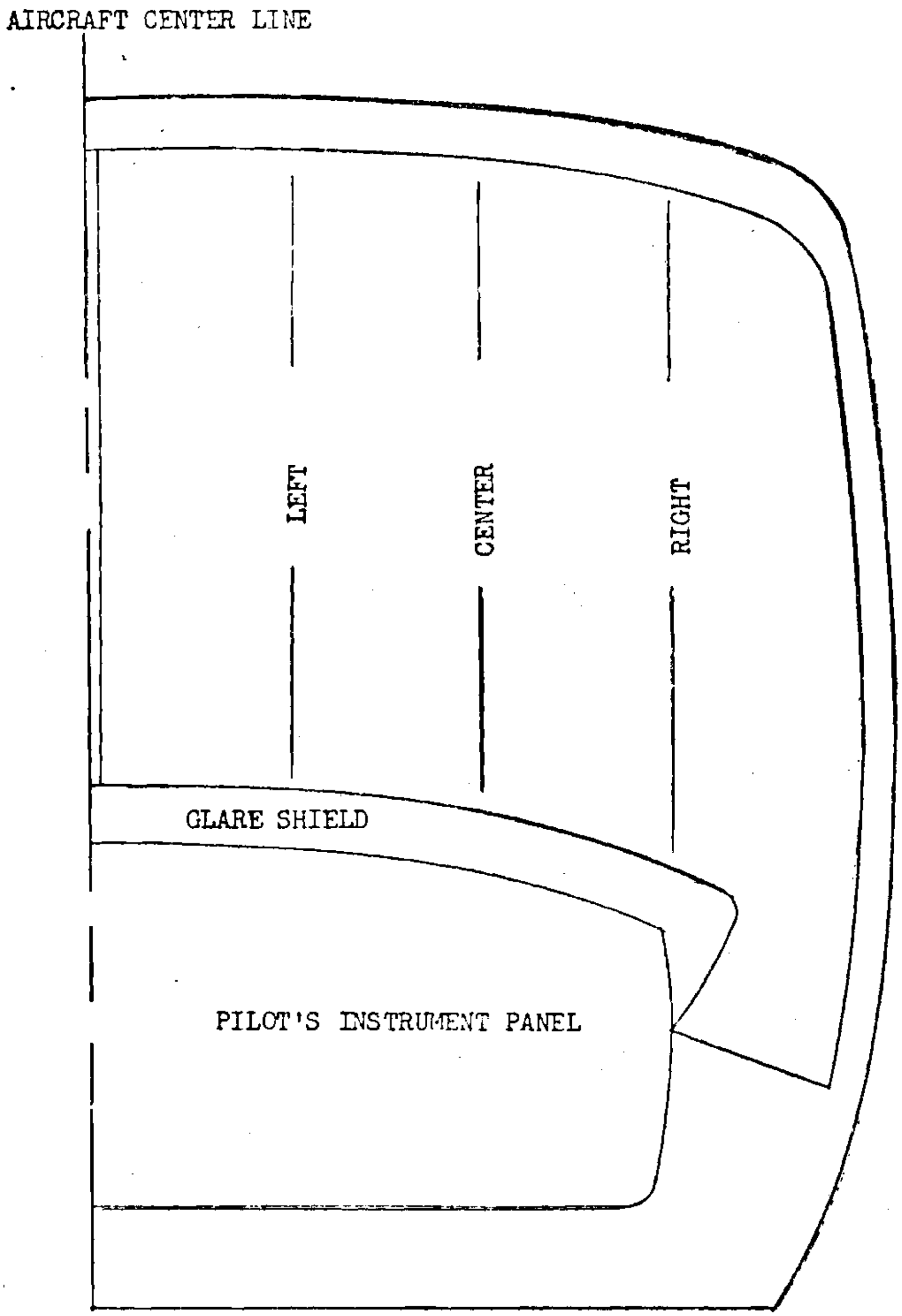


Figure 15 a. Field of View

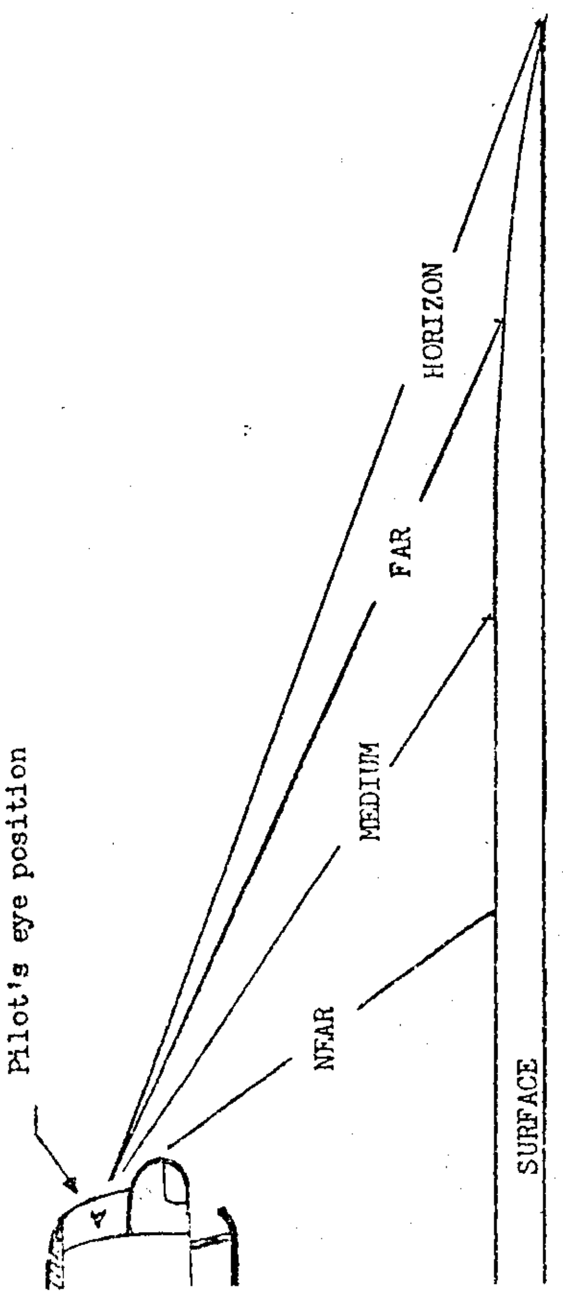


Figure 15 b. Field of View

windshield (DLE)

R - Right, distance same as for L

F - Far, 3/4 of the distance to the Horizon or edge of view (DTH)

M - Medium, $\frac{1}{2}$ DTH

N - Near, $\frac{1}{4}$ DTH

AL - Ahead Left, $\frac{1}{4}$ DRE

AR - Ahead Right, $\frac{1}{4}$ DLE

FL - Far Left, 3/4 DLE

FR - Far Right, 3/4 DRE

LER_n - Left edge of runway

CR_n - Center of Runway

The tables showing results for instrument maneuvers will show several instruments a group of instruments as a fixation point. When two instruments are "grouped," this fixation point is halfway between the two. When more than two instruments are "grouped" together, the point is identified by name. These points are depicted on Figure 16. These fixation points with multiple instruments included are examples of how peripheral vision is used to lighten the workload of the pilot.

The tables described above were used to determine "link values." "Link values" are measurements of eye movement between various instruments by analyzing the transition, and are considered an indication of the goodness of the instrument panel layout. These values can be expressed as:

Link value $\equiv Qij = qij + qji$ where qij & qji are one way link values

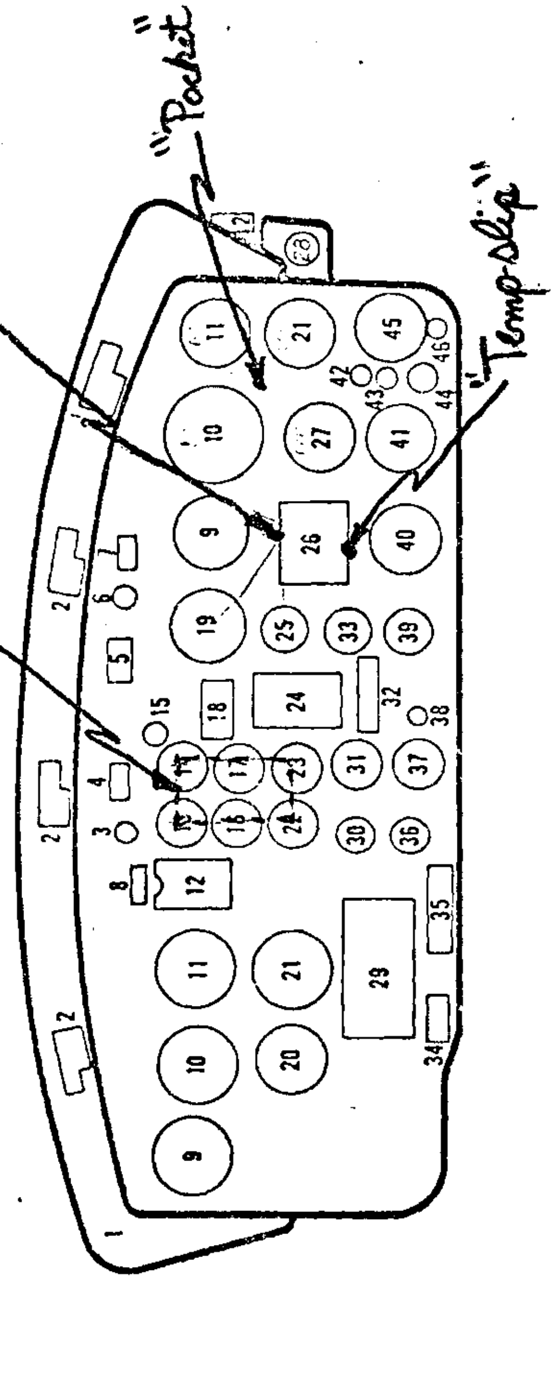


Figure 16. Fixation Points

$$qij = \sum_{k=1}^{N} gijk \quad (N = \#\ \text{transitions from i to j})$$

$$qji = \sum_{k=1}^{M} qjik \quad (M = \#\ \text{transitions from j to i})$$

Tables of the link values are contained in Appendix B, Figure 17 is an example.

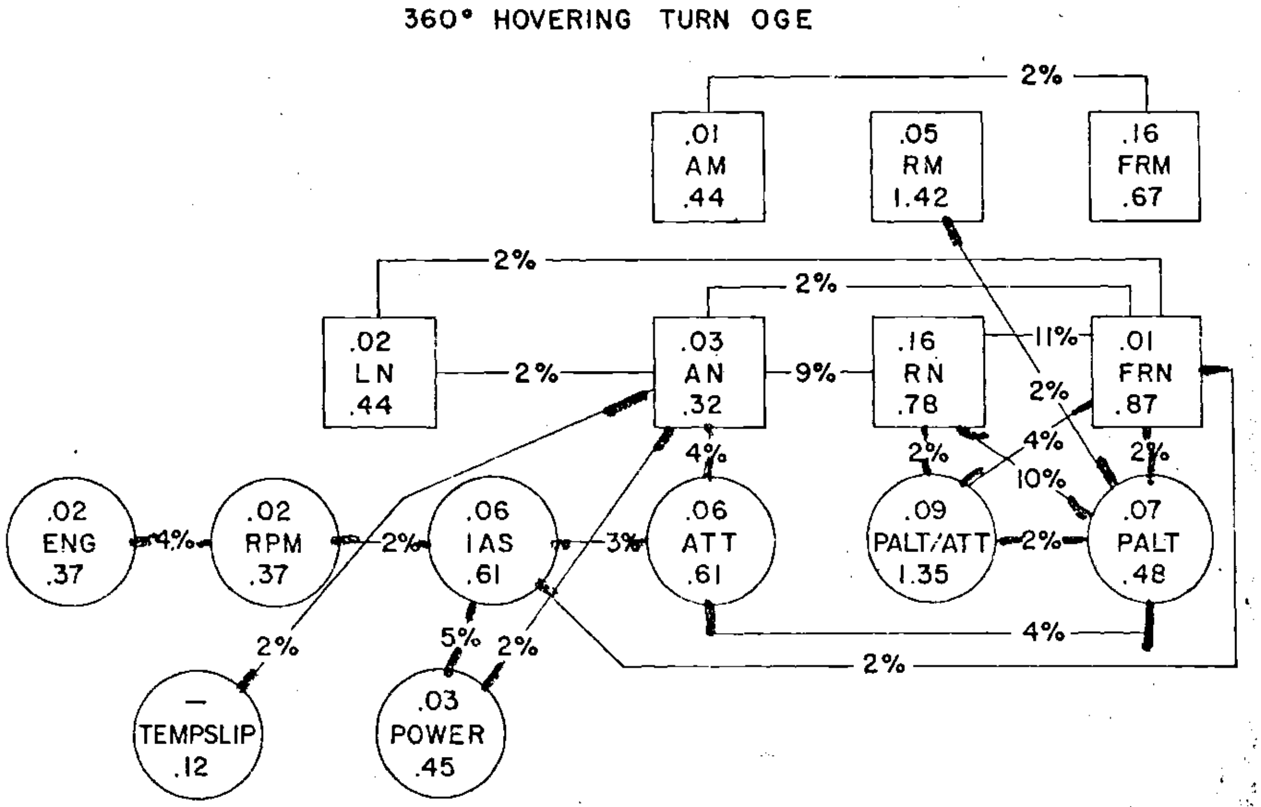


Figure 17. Link Values

CHAPTER V

RESULTS AND ANALYSIS

Examples

The following figures are examples of the instrument panel layouts obtained from the methodological techniques used in this research. Figure 18 is a layout obtained from the PLANET routine. Figure 19 is the initial input for the modified CRAFT program, as mentioned in the preceeding chapter, and Figure 20 is the final configuration obtained. The remaining panel layout printouts are included in Appendix A.

Comparison of Computer Results with Standard Practices

The layouts generated by the computer programs were analyzed with the assistance of experts from the Avionics Laboratory at Fort Mommouth, New Jersey and reviewed by supervisory personnel from AMSAA at Aberdeen Proving Ground, Maryland. The procedure used contains two phases. The first phase consisted of an objective ranking of three indicators of the overall effectiveness of the computer produced layouts and associated weighting factors. The second phase consisted of a subjective critique on application of using these programs in the army's new design process.

In the first phase, a factor chart was compiled as shown on page 50.

The measures of effectiveness used were relative amount of eye

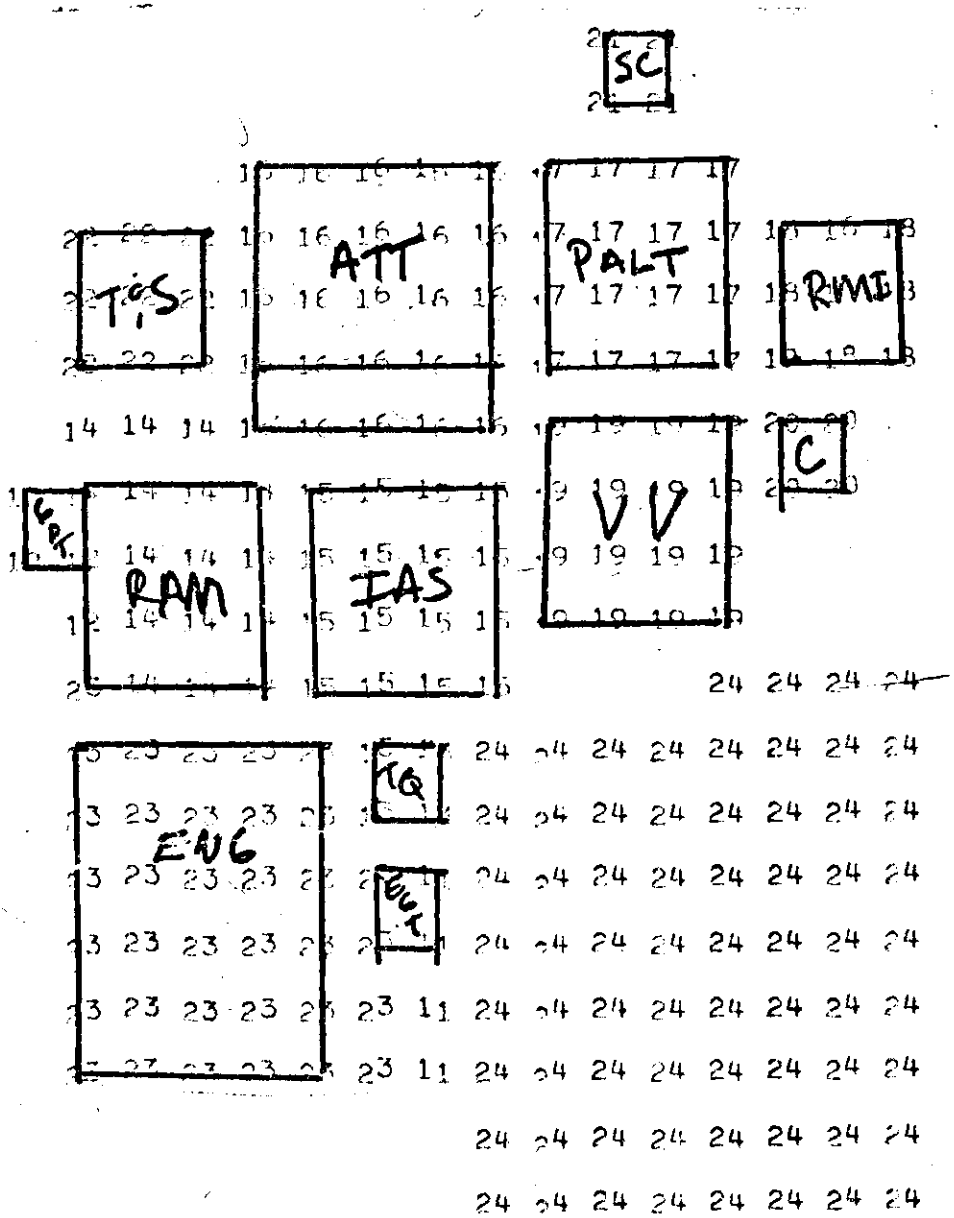


Figure 18. Panel Layout

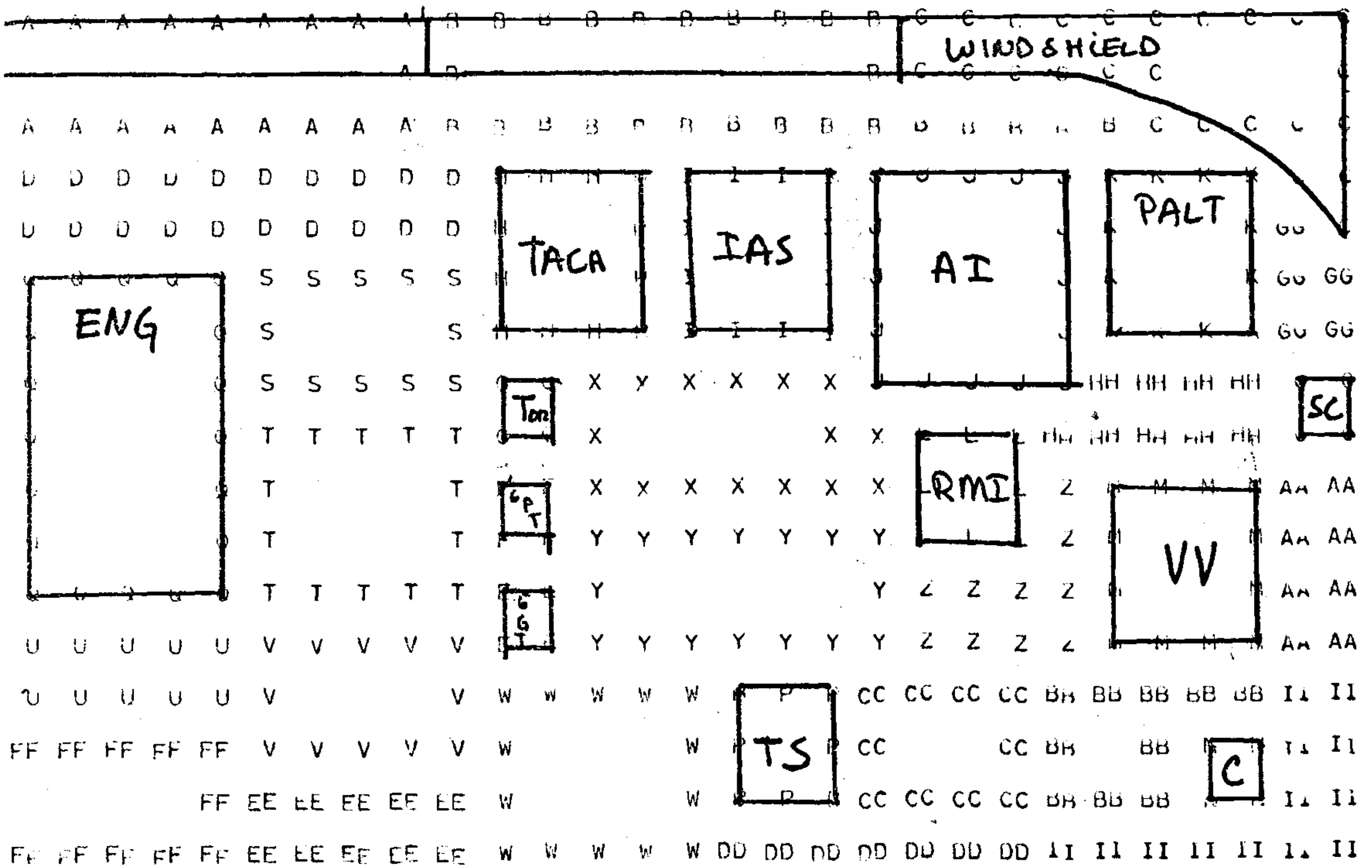


Figure 19. Panel Layout

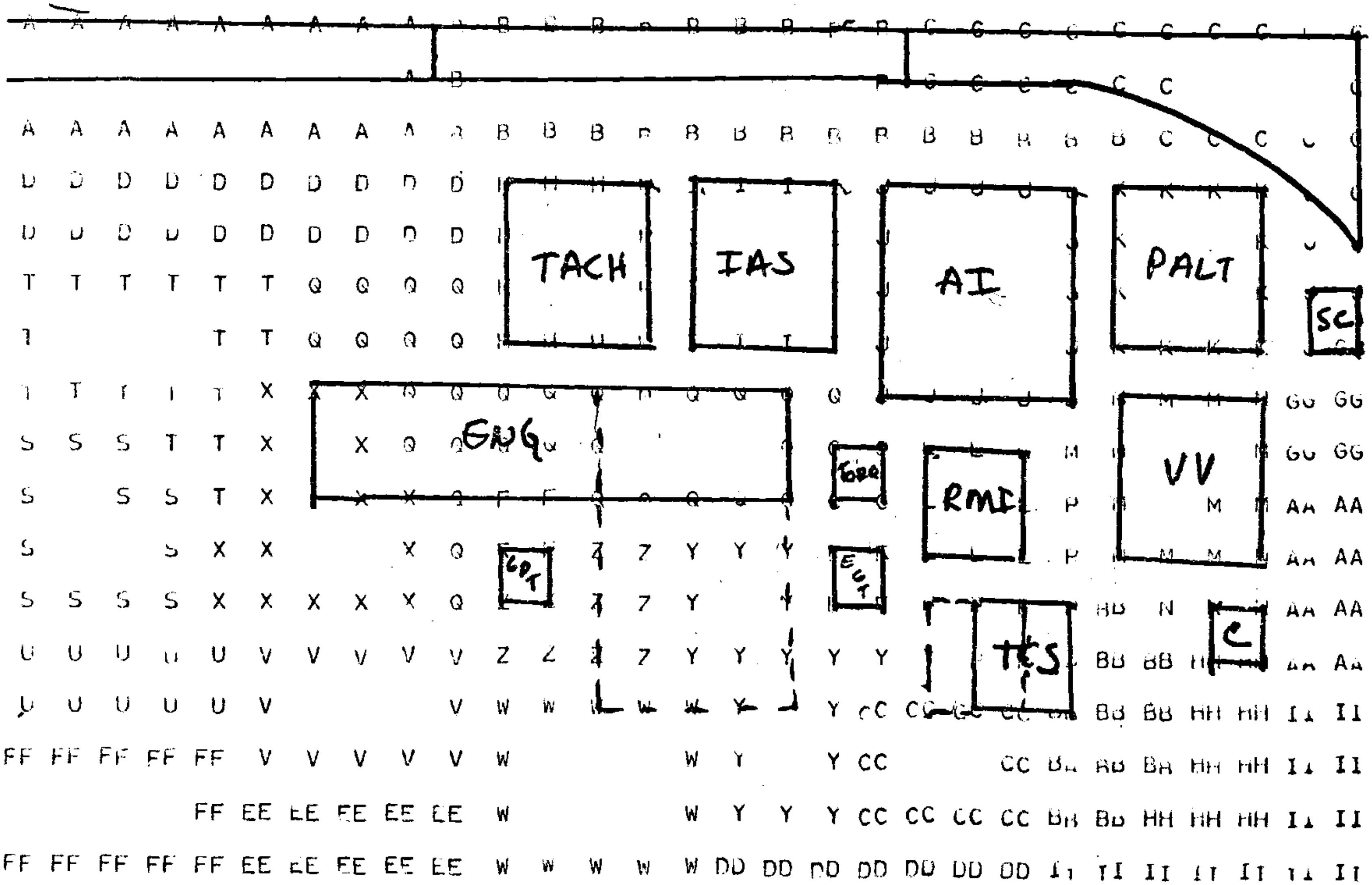


Figure 20. Panel Layout

MEASURES OF EFFECTIVENESS	WEIGHTING FACTOR	PRESENT		CRAFT		PLANET	
		RATING	WEIGHTED RATING	RATING	WEIGHTED RATING	RATING	WEIGHTED RATING
EYE MOVEMENT	.243	2.0	.486	6.0	1.458	4.0	.972
EXPERT'S OPINION	.312	2.5	.78	5.0	1.56	3.75 (4.83)	1.17 (1.50)
PILOT'S OPINION	.443	4.2	1.86	5.1	2.26	4.33 (3.83)	1.918 (1.70)
OVERALL RATING		3.13		5.28		4.06 (4.18)	

movement involved, the expert's opinion of the layout produced, and a study of pilot's opinions of the layouts. Seven pilots were interviewed and they had 3200 hours average flying time and 8 years average experience. The grades for the various measures of effectiveness were obtained from this ranking guide.

0.0

1.0 very low

3.0 low

5.0 average

7.0 high

9.0 very high

10.0

The weighting factor was obtained by asking each person interviewed what was the relative importance of each measure of effectiveness using the above ranking guide, and then normalizing the results to obtain a fraction.

It is important to note that the current instrument panel on the UH-1B was rated below all the computer generated layouts in all but two cases. From the analytical standpoint of using the above table, CRAFT seems to be better suited for producing layouts with a rating of 5.28 versus 4.06 for PLANET, however, when PLANET was used as a guide to instrument placement rather than using the layout as presented in the output, it received equally high ratings as CRAFT from the experts. This was partially due to the building method of PLANET producing square layouts while the designers and especially the pilots are only used to looking at rectangular layouts with fixed references. These ratings are included in parentheses on the table. Even though the CORELAP program was not operating properly, the consensus of the expert's opinions was that CORELAP was generally producing the same quality layout as PLANET. This probably occurred because the layouts were produced around the attitude indicator which is traditionally the centered instrument on the panel, thus giving the appearance of layouts similar to the one's produced by PLANET, and what they were used to seeing.

The second phase, the subjective critique, was extremely favorable to using this technique as an aid in the design process because it provided more alternatives to the designer and could give quantitive results. The only reservation of the experts was the difficulty of building a data base for these programs on a large scale project. They suggested further research into this area, but were convinced that it would not present any real problem. A natural use for this technique is in Phase II, preliminary mockup stage, of the new design phase. The experts felt that using the PLANET and CRAFT layouts together would give the designer the relationship between instruments and a possible layout configuration for the panel for this preliminary mockup.[3,8]

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions and Recommendations

The purpose of this thesis has been to evaluate the usefullness of three facility allocation algorithms when applied to instrument panel layout design. But in a broader sense, this study has approached the class of man-machine interface problems with traditional operations research techniques. Within the confines of the purpose of this thesis, it has been shown that these algorithms can be used effectively in designing instrument panels as another tool in the design process. They are already available, easily adapted to this purpose, and give effective results. It was found that both programs were equally well suited in the design process. PLANET provided more information on instrument relationships while CRAFT constructed a better configuration for layout purposes, thus both should be used in conjunction with one another. Since CORELAP did not run correctly, no decisive conclusion can be made about its role.

From the viewpoint of integrating this into the new design methodology of the army the experts at the Avionics Laboratory at Fort Monmouth felt this could be used effectively if the data base on eye movement could be effectively handled.

The excellent results achieved with this technique tends to support the Hitchings, Freund, and Sadosky criteria of using minimum eye movement.

It is also possible to glean information from the computer generated layouts themselves. The layouts produced support the contention of many designers that the EGT gauge and torque meter should be associated with the primary flight instruments. It is also worthwhile to note that a layout was produced with lesser eye movement than a layout using the "basic T" (Appendix A). Other inferences can be drawn from the layouts, however, these will be left to the panel designers for further evaluation.

Limitations

There are two basic limitations that effect this methodology. The most significant is the data for the link values. The study from HEL that was conducted was very limited in scope and in the size of the experiment conducted. Only two mission profiles were flown without having the opportunity to test many pilots under different conditions. The entire output of the computer programs is based on that small experiment. The second limitation is not being able to validate the computer layouts by the most significant means, under controlled conditions.

Further Research

Since it was found that CRAFT and PLANET should be used in conjunction, further research should be done in considering these two programs together to provide a flexible design tool with the end result including computer graphics for immediate feedback and design changes.

However sophisticated the computer aided design becomes, the most important area for further research is in the area of obtaining eye movement data and pilot information requirements. Since the programs are only as good as the data and assumptions used to implement them.

APPENDIX A

This appendix contains the raw data as taken from the films of the emc-2 camera that was used to construct the data tables and panel layout configurations obtained from the computer programs.

Frame #

Instruments

Frame #					
1398	Pocket				
.	AS	RPM	TQ		
1400	"	"	"		
.	—	—			
.	Eng	Inst			
.	"	"			
.	"	"			
.	AS				
.	"				
.	AI				
.	"				
.	Pocket				
1410	"				
.	Alt				
.	"				

	Pocket				
	"				
	"				
	—	—			
	AI				
	Alt				
	VV				
1420	—	—			
	—	—			
	Pocket				
	AI				
	AS	RPM	TQ		
	"	"	"		
	Eng	Inst			
	"	"			
	"	"			
	TQ	GPt			
1430	—	—			
	—	—			
	AI				
	"				
	Pocket				
	"				

	Frame #	Instruments			
	1436	"			
		"			
		Alt			
		"			
	1440	"			
		"			
		"			
		"			
		Pocket			
		A5			
		"			
		"			
		Pocket			
		"			
	1450	"		at 1500'	
		"			
		"			
		"			
		A5			
		"			

		Alt		
		AS		
		"		
		AS	TG	RPM
	1460	AS	"	"
		"	"	"
		"	"	"
		"	"	"
VV=0		"	"	"
		AS		
		Alt		
		"		
		VV		
		VV		
→	1470	Alt	Acft	level @ 1500'
		AI		
		"		
	[illegible]	[illegible]		

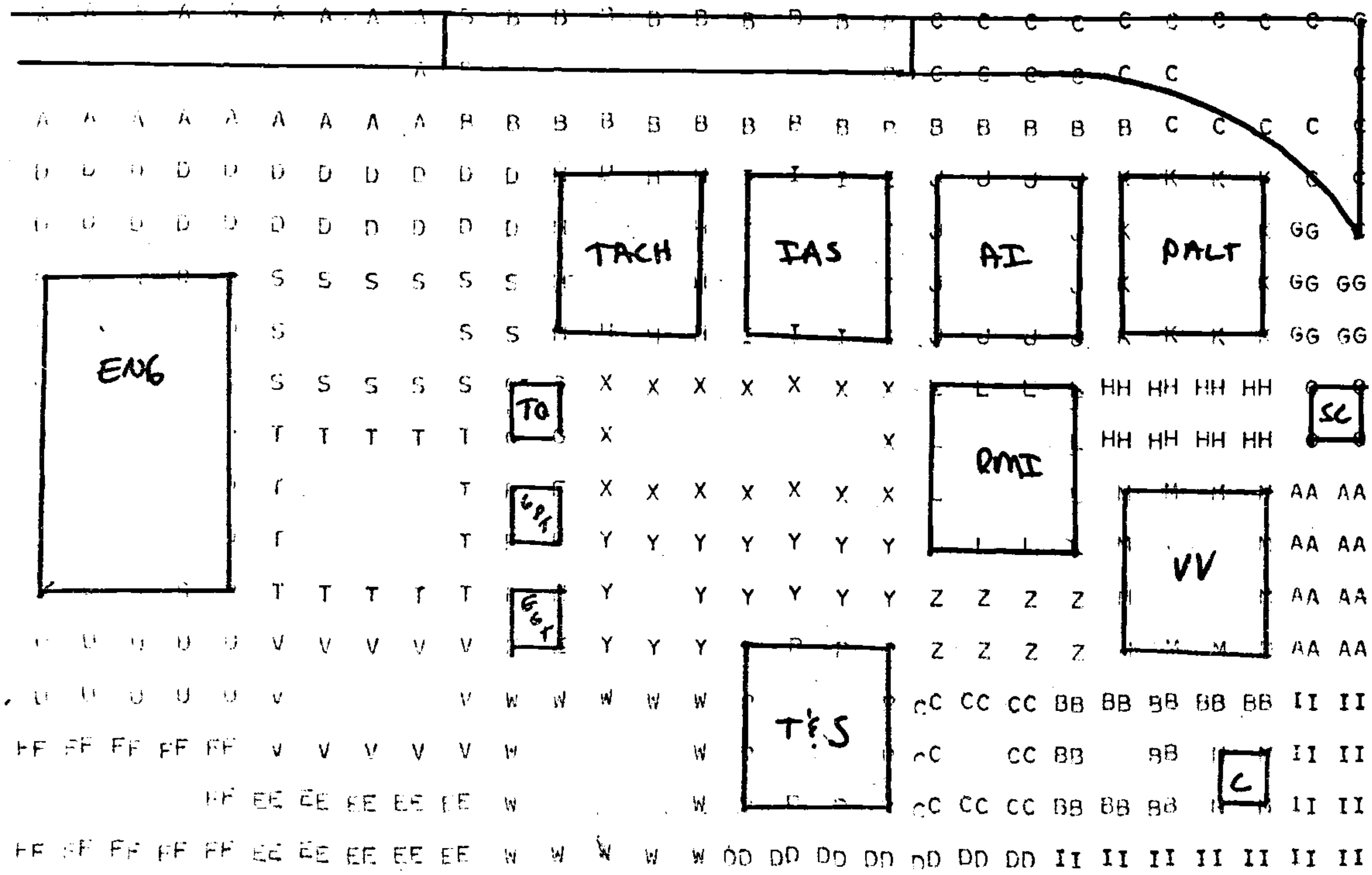
Instruments

Frame #					
1323	Eng	Inst			
		—			
	RPM	TΘ	AS		
	"	TΘ	"		
	"	"	"		
	AS				
	AI				
1330	"				
	Alt	—			
	"				
	VV	Comp			
	VV				
	Alt				
	Alt				
	"				

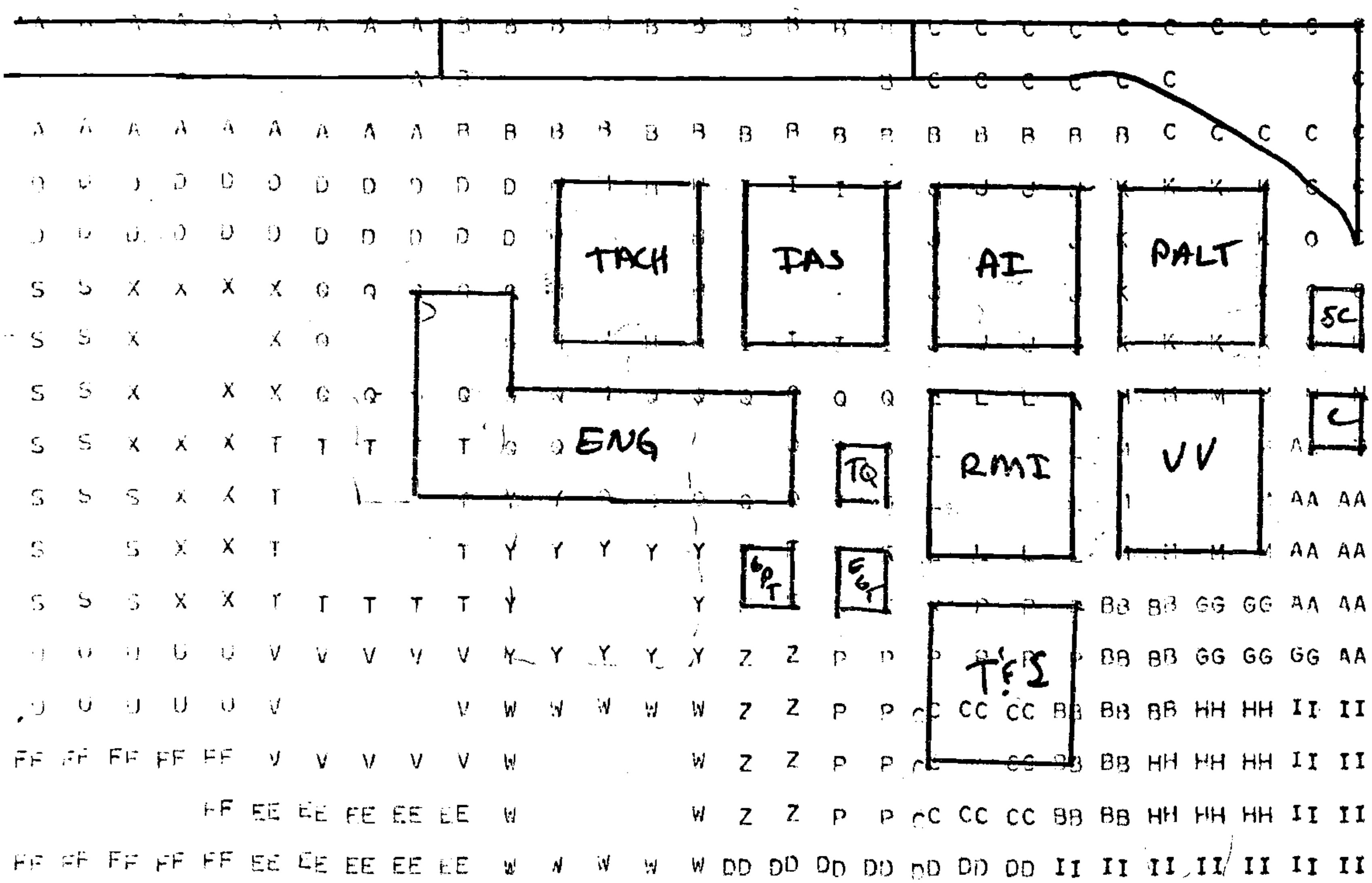
	V V
	V V
1340	Pocket
1340	"
	AI
	"
	"
	"
	"
	Alt
	"
	V V
1350	V V
	V V
	V V
	V V
	V V
	"
	— —
	Pocket
	"
	"
[illegible]	"

Frame #	Instruments		
1361	AH		
	"		
	Pocket		
	"		
	"		
	Alt		
	—		
	Pocket		
	"		
	AI		
1370	"		
	Alt		(Alt 1250' Mid Pt in Cl.
	"		
	VV		
	"		
	VI		
	AS		

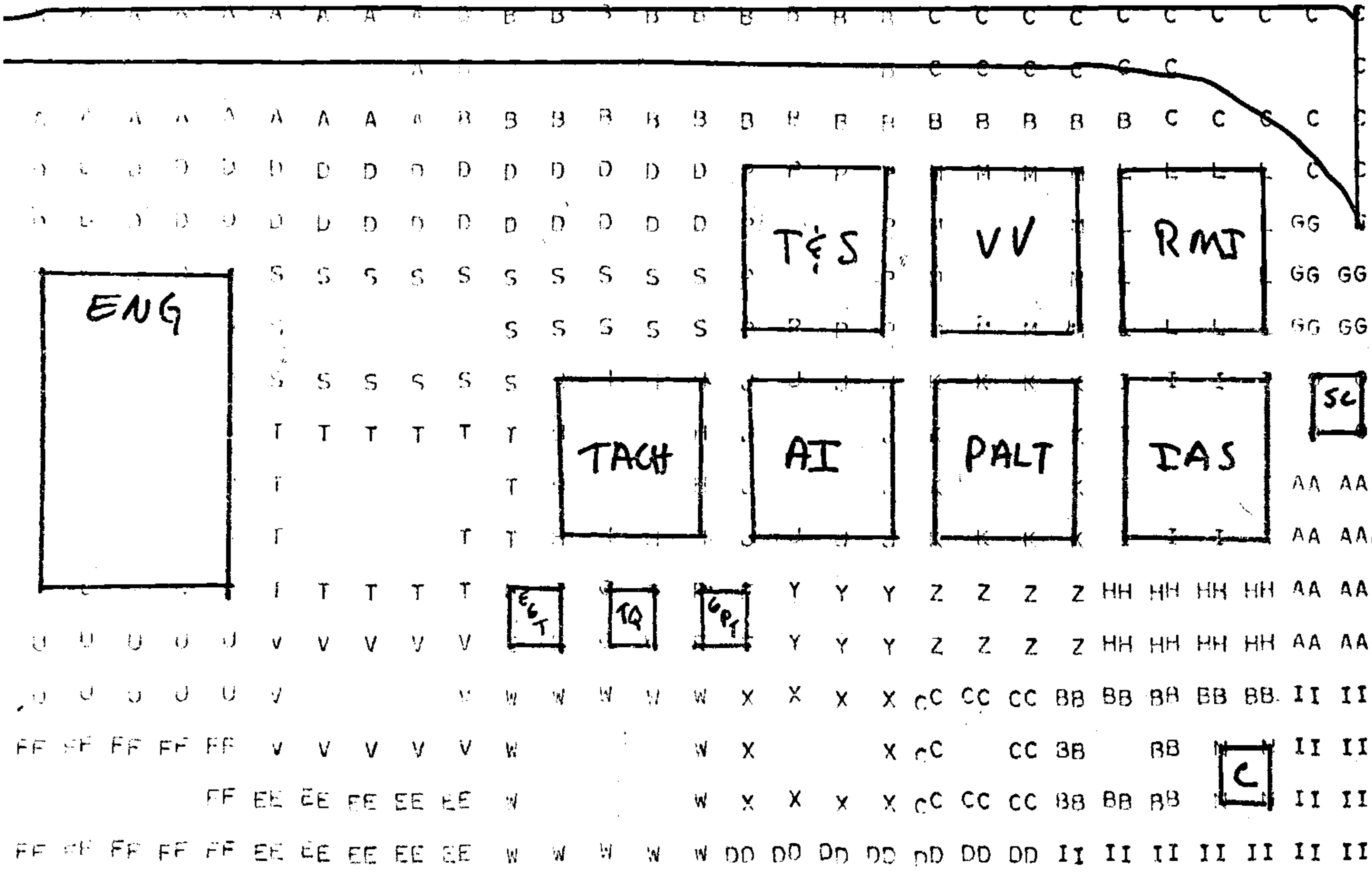
	.	—	—	(Moving)
	.	Eng	InsT	
	.	"	"	
	1380	TQ	RPM	AS
		GPT	EGT	Tbs
		TQ	RPM	AS
		"	"	"
		AI		
		"		
		—	—	
	.	Alt		
	.	VV		
	.	Alt		
	1390	"		
	.	Pocket		
	.	"		
	.	"		
	.	AS		
	.	"	RPM	TQ
	.	"	"	"
	[illegible]	[illegible]		



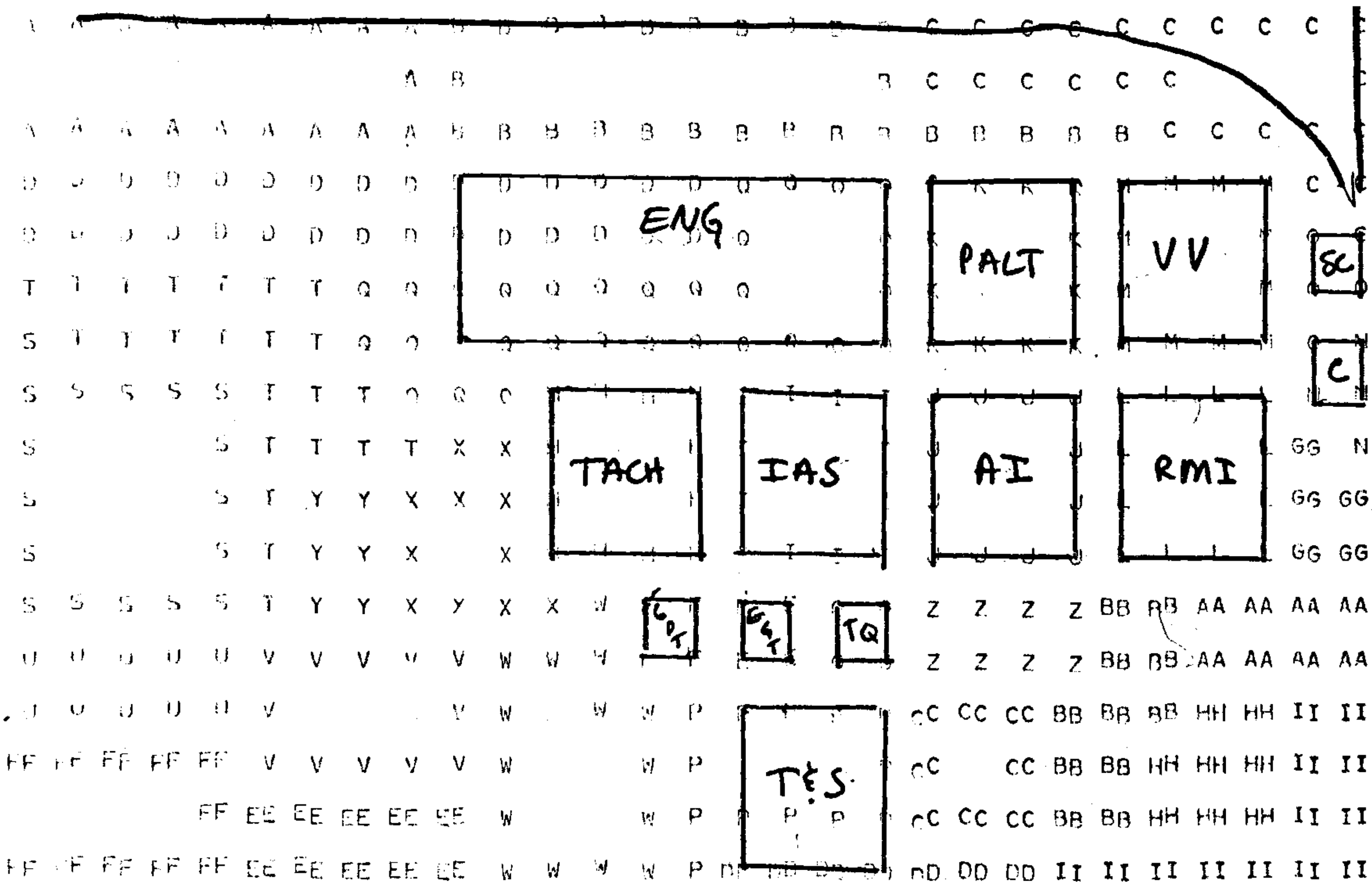
COST 74.35 EST. COST REDUCTION .00 MOVEA MOVEB MOVEC ITERATION



COST 55.04 EST. COST REDUCTION .22 MOVEA N MOVEB AA MOVEC GG ITERATION



COST 81.20 EST. COST REDUCTION .00 MOVEA MOVEB MOVEC ITERATION



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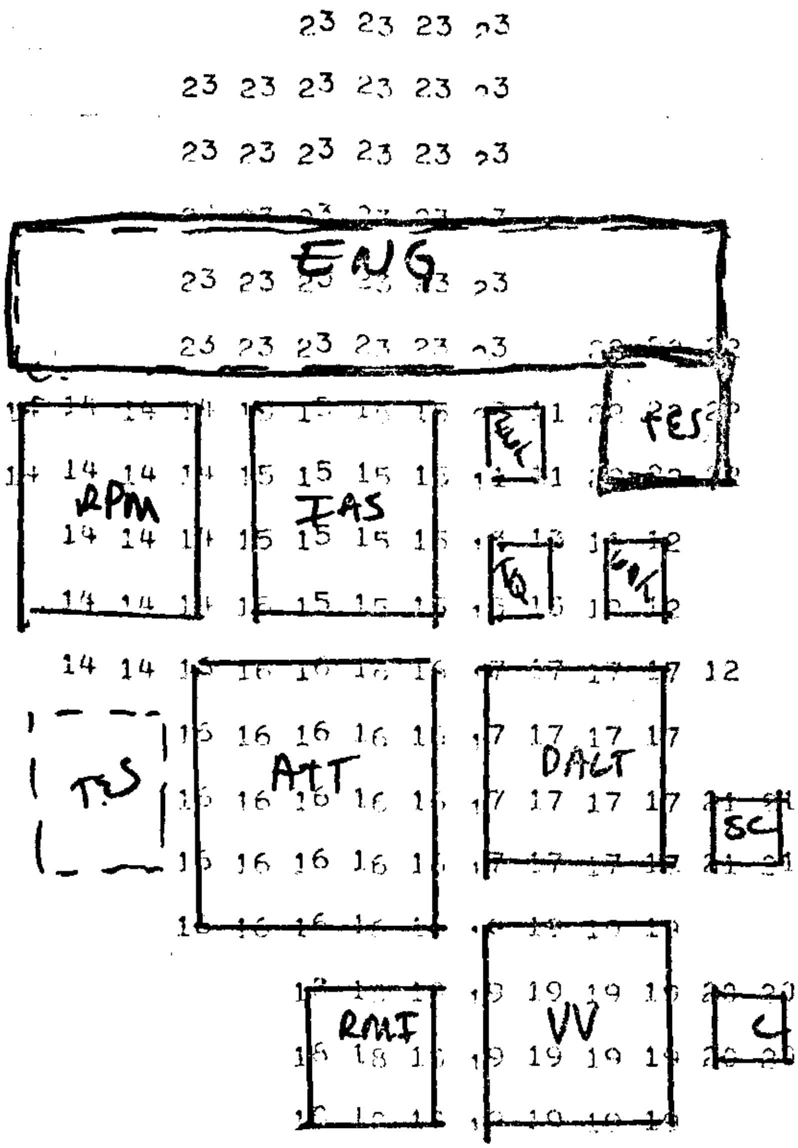
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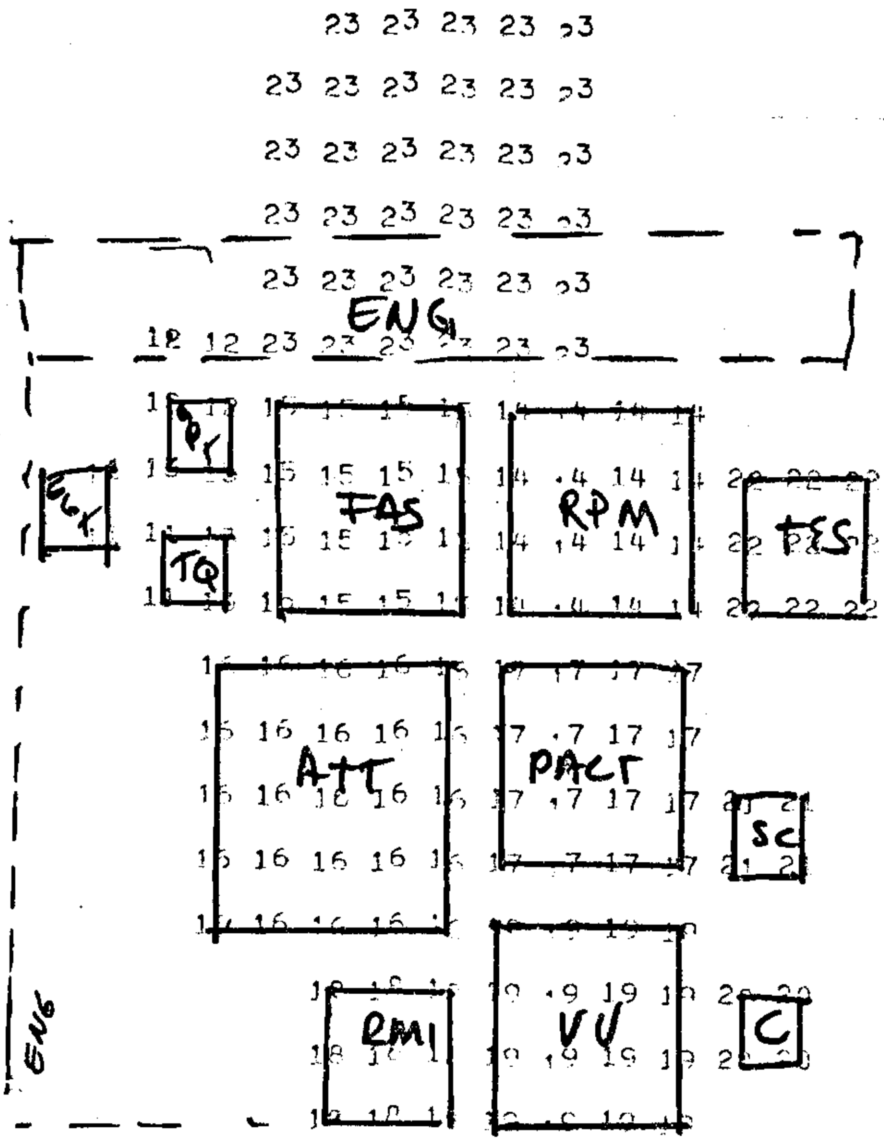
RPM
IAS
TES
ATT
DALT
SC
RMI
VV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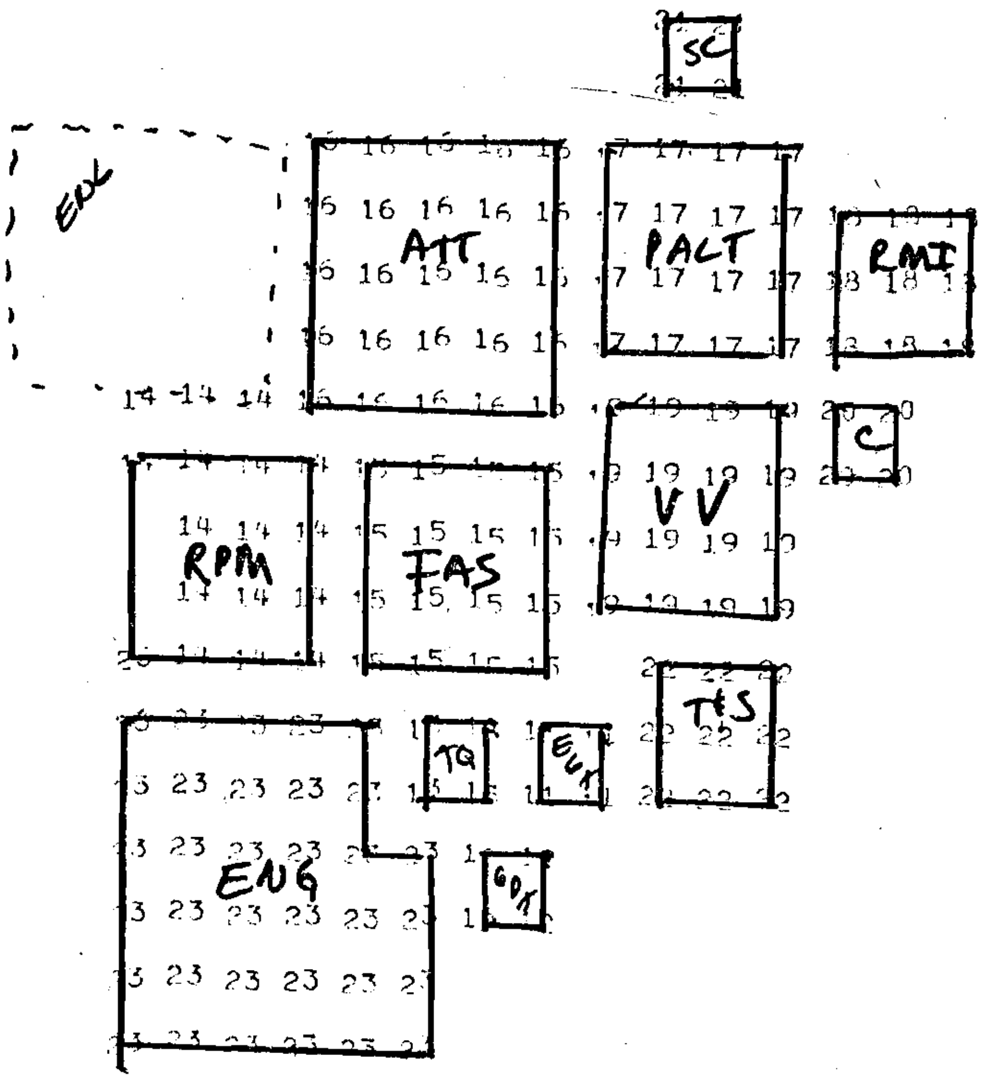
FES
TQ
ATT
PACT
SC
RMI
VV
C
ENG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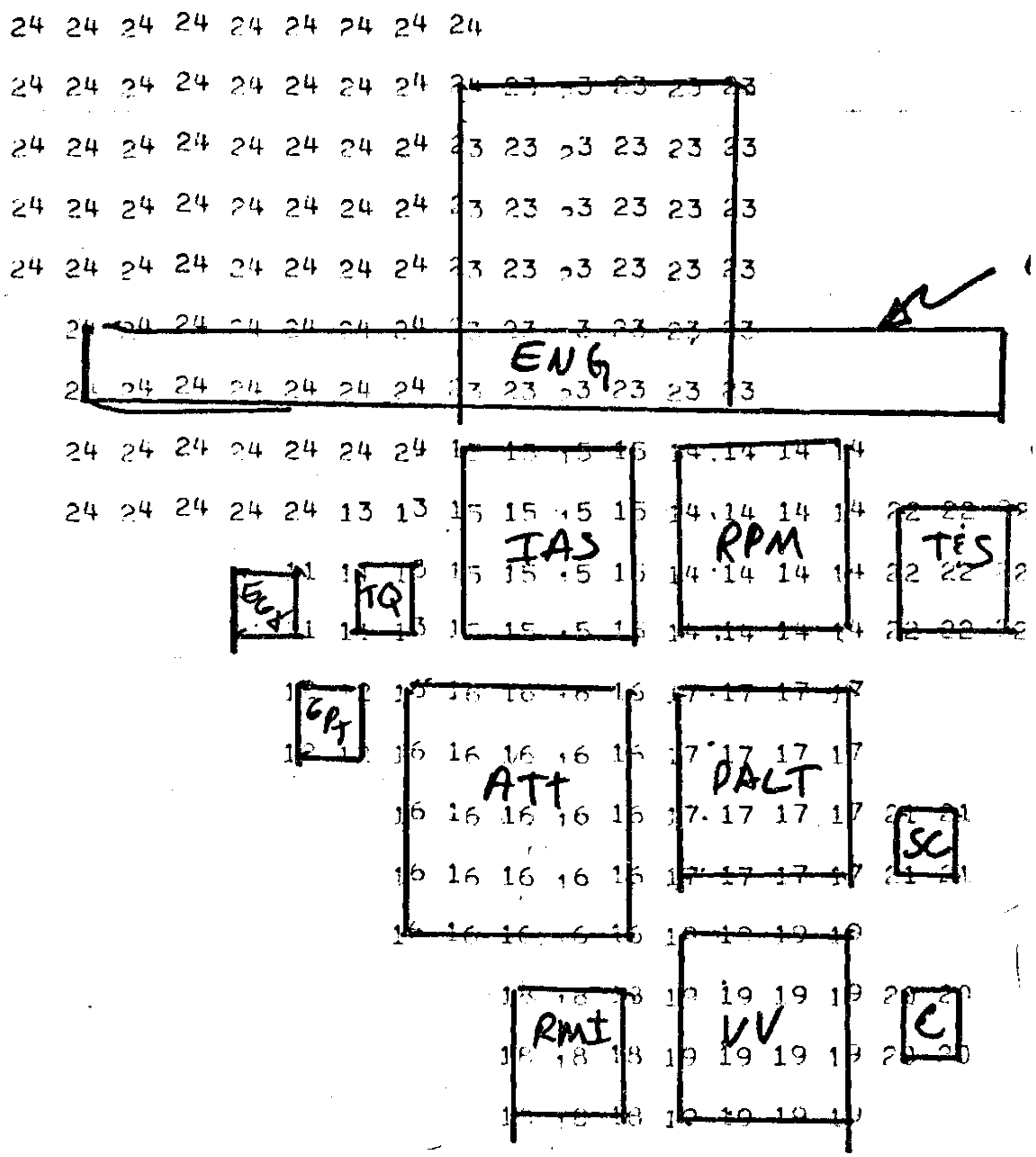
ATT
PALT
RMI
C
VV
RPM
FAS
TQ
TES
ENG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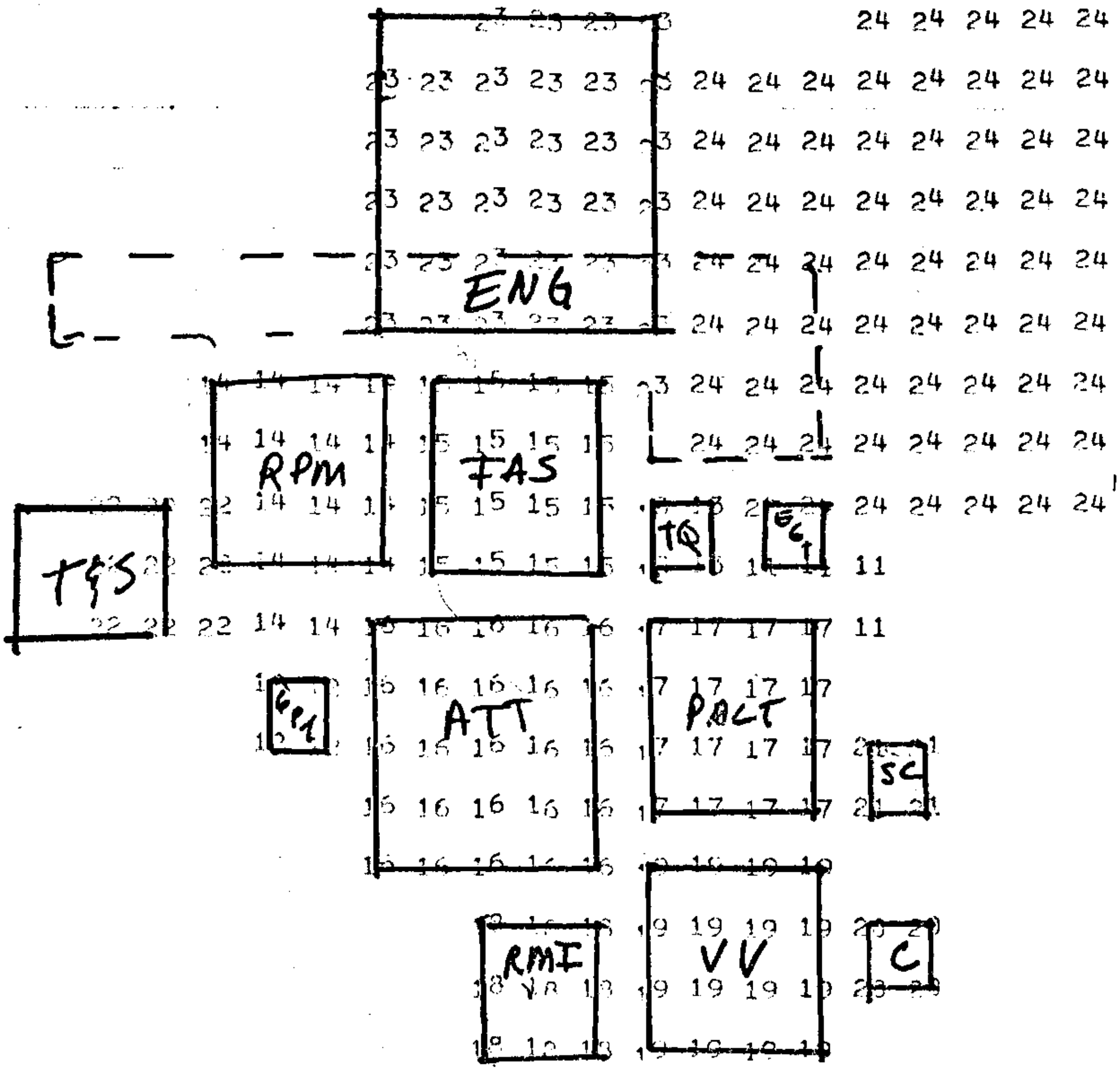
IAS
RPM
TES
TQ
ATT
DALT
SC
RMI
VV
C


ENG
RPM
IAS
T&S
TQ
ATT
PACT
SC
RMI
VV
C

APPENDIX B

Appendix B contains examples of the data tables constructed from the film data and the link values of the instruments.

IFR Hover IGE

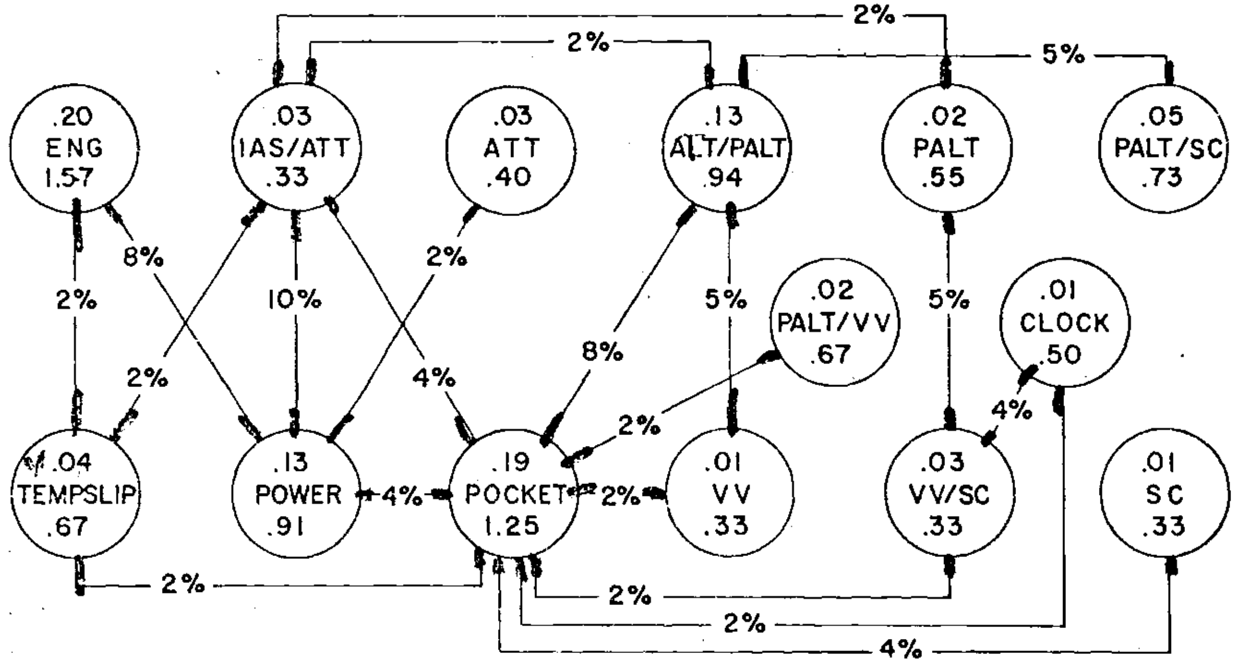
FIXATION POINT	Ni	$\overline{Td}$	$\overline{fs}$	n	Ti
ATT	5	.40	.06	.03	.00
PALT	3	.55	.04	.02	1.67
VV	2	.33	.03	.01	.67
Engine Group	10	1.57	.13	.20	15.67
Power	11	.91	.14	.13	10.00
Pocket	12	1.25	.16	.19	15.00
ATT, IAS	7	.33	.09	.03	2.33
ATT, PALT	11	.94	.14	.13	10.33
Temp-slip	5	.67	.06	.04	3.33
SC	3	.33	.04	.01	1.00
Clock	2	.50	.03	.01	1.00
PALT, VV	2	.67	.03	.02	1.33
SC, VV	7	.33	.09	.03	2.33
PALT, SC	5	.73	.06	.05	3.67
Nu	20	.33	.26	.09	6.67

Climb IFR

FIXATION POINT	Ni	$\overline{Td}$	$\overline{fs}$	n	Ti
ATT	26	.57	.17	.10	14.73
PALT	36	.58	.24	.14	20.74
VV	21	.65	.14	.09	13.69
IAS	31	.47	.20	.10	14.66
RPM	17	.49	.11	.05	8.34
TQ	5	.33	.03	.01	1.67
Engine Group	7	.95	.05	.04	6.67
Power	9	.81	.06	.05	7.33
Pocket	21	.76	.14	.10	15.97
ATT, IAS	4	.40	.03	.01	1.99
PALT, VV, SC	10	.57	.07	.04	5.71
Temp-slip	6	.39	.04	.02	2.33
RMI	5	.53	.03	.02	2.65
SC	3	.33	.02	.01	1.00
Nu	103	.33	.67	.23	34.52

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

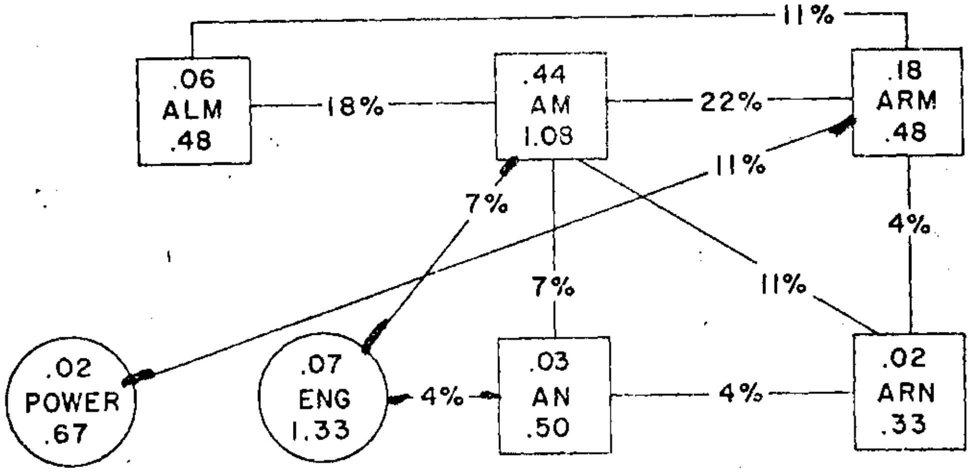
IFR HOVER IGE



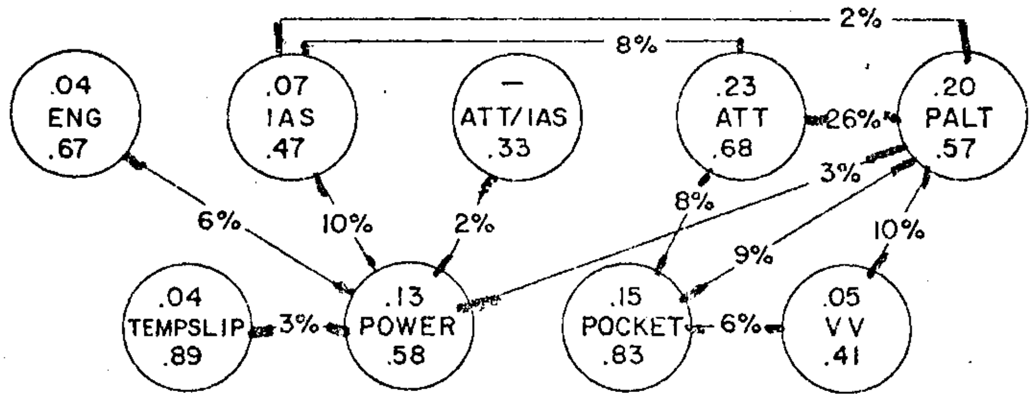
VFR Hover IGE

FIXATION POINT	Ni	$\overline{Td}$	$\overline{fs}$	n	Ti
RM, CRn	1	.67	.03	.02	.67
RN, CRn	2	.33	.05	.02	.67
RM, LERn	7	.48	.18	.08	3.33
LM, LERn	5	.48	.13	.06	2.33
LN, LERn	1	.33	.03	.01	.33
AM, CRn	1	.67	.03	.02	.67
AN, CRn	2	.50	.05	.03	1.00
AM, LERn	16	1.08	.41	.44	17.33
Power	1	.67	.03	.02	.67
Engine Group	2	1.33	.05	.07	2.67
Nu	28	.33	.72	.24	9.33

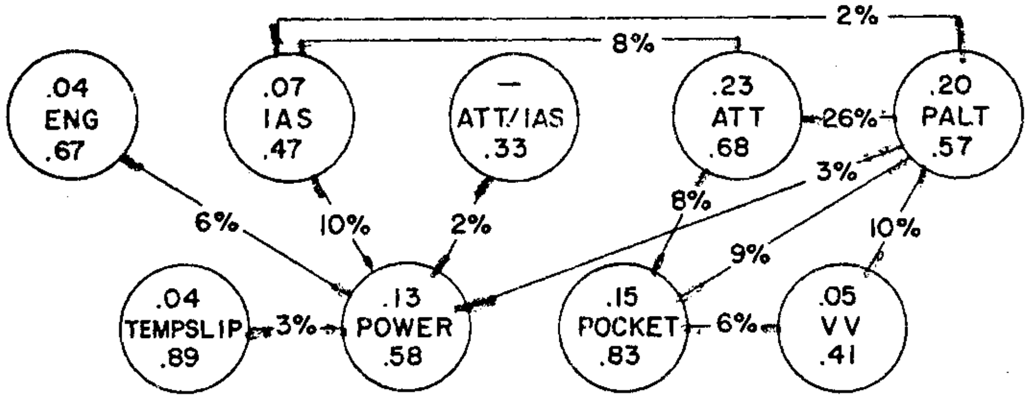
VFR HOVER IGE



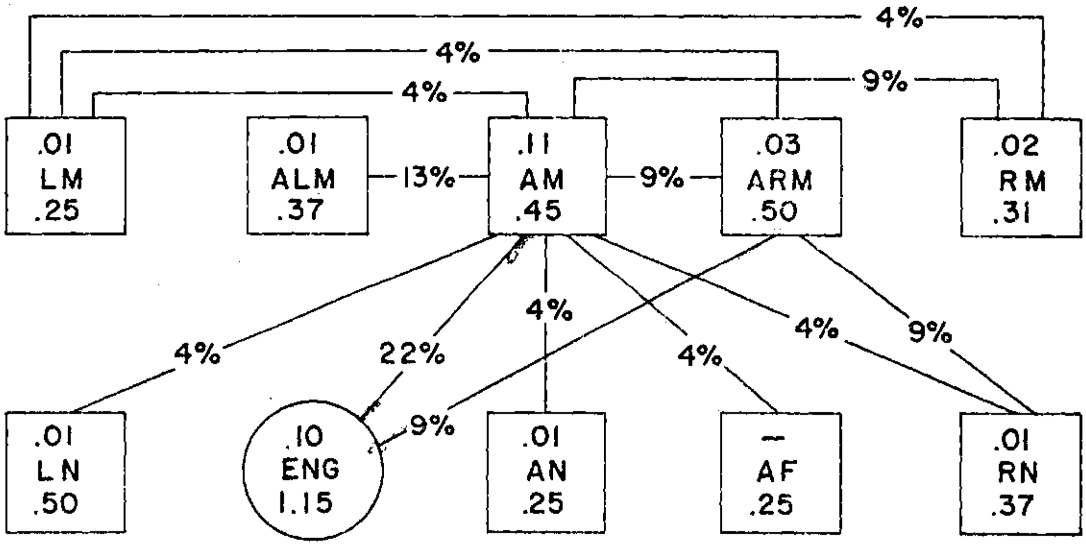
IFR HOVER OGE 500'



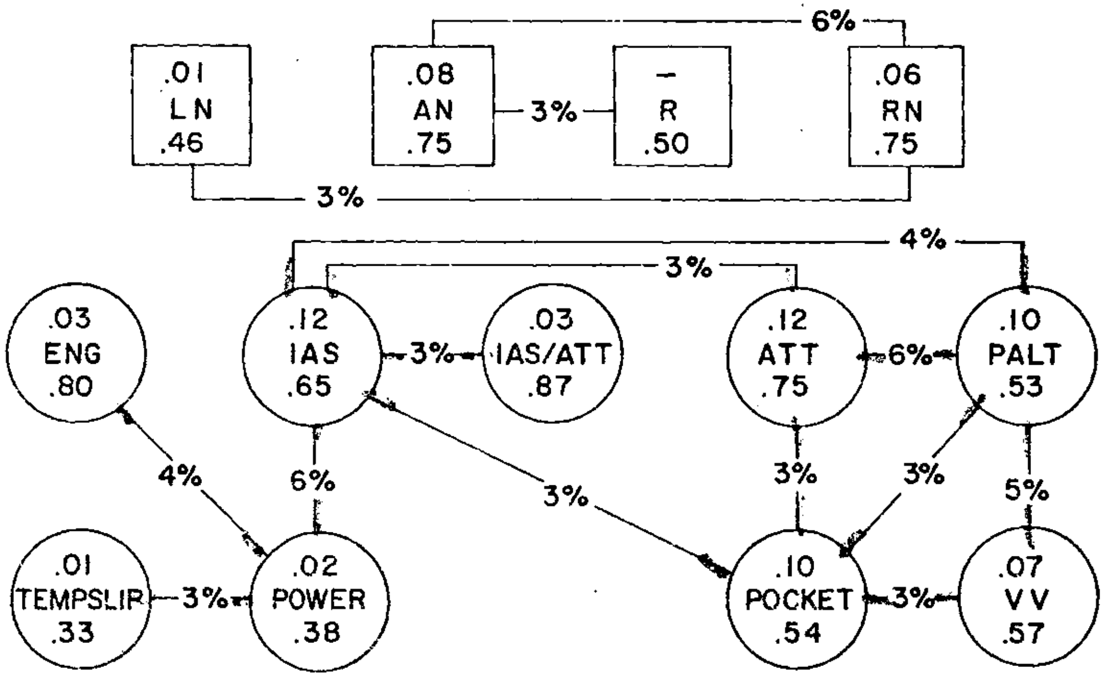
IFR HOVER OGE 500'



VFR CLIMB



VERTICAL DESCENT



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